UNIVERSITY OF MISSOURI

ENGINEERING EXPERIMENT STATION

BULLETIN, NO. 1.

ACETYLENE FOR LIGHTING COUNTRY HOMES

BY
J. D. BOWLES.

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THE UNIVERSITY OF MISSOURI
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The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1st, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and two research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

ACETYLENE FOR LIGHTING COUNTRY HOMES.

The farm home may be readily equipped in these days with every modern convenience. One of the most important of these conveniencies is a good lighting system. The oil lamp with its accompanying dirt, inconvenience, and danger, may be replaced, with the outlay of a few hundred dollars, by a lighting system almost equal in convenience and economy to a city lighting service.

Private Lighting Systems are divided into three classes: Acetylene, Gasolene, and Electric. This bulletin is the first of a series devoted to these systems; the others, Gasolene Lighting Systems and Small Private Electric Installations are in preparation.

Those who are interested may make their own comparison of these systems as to relative economy, convenience and practicability, when the series has been published.

This bulletin contains a brief discussion of the properties of Acetylene and of the Calcium Carbide from which it is derived when the carbide is brought into contact with water. The details of Acetylene Generation and of Acetylene Generators are studied, as well as the planning of a typical lighting arrangement in which are taken up in detail the factors governing the size and number of burners, the capacity of generator required, piping and fixtures, and the value of scientific shading and diffusing of the light where satisfactory illumination is desired. Cooking and heating by Acetylene is discussed briefly. The Design of a complete Installation is worked out in detail giving cost data. Village and Town Lighting Systems are briefly discussed. The appendix contains the results of tests made by the Station, a schedule of pipe sizes, and a table of dimensions and costs of Acetylene Generators, together with the list of Generators approved by the National Board of Fire Underwriters.

Useful information and data were obtained from the Acetylene Journal (Chicago) and Professor George Gilbert Pond's bulletin on Calcium Carbide and Acetylene published by the Pennsylvania State College.

The tests described were made with a 35 light Carbide Feed Generator furnished by the Eagle Generator Company of St. Louis.

The writer is indebted to Mr. K. A. McVey of the Experiment Station Corps for assistance in making the tests.

CALCIUM CARBIDE.

Calcium Carbide is the substance from which Acetylene gas is produced. It was first prepared on a promising commercial scale in 1892 by Thomas L. Willson, a young electrical engineer at Spray, North Carolina. Willson utilized the intense heat of the electric furnace, operating

on a mixture of lime and coal tar. His search was for something an entirely different nature and the discovery of Calcium Carbide ai its remarkable property of producing Acetylene gas when in contact wi water was purely by chance.

The Commercial Carbide is now prepared by incorporating a mi ture of ground coke and lime in the proportion of 41.7 per cent ai 58.3 per cent, respectively, and introducing the mass into an electr furnace where the intense heat causes chemical reactions to take pla yielding 69.7 per cent of calcium carbide and the remaining 30.3 p cent as carbon monoxide which is burned at the mouth of the furnace.

Calcium Carbide is a dark gray substance more or less crystalli in structure and very hard and brittle. A cubic foot of crushed carbi weighs about 136 pounds. It may be heated to redness or higher wit out suffering any change. It is not affected by shock or concussion ar may be preserved indefinitely when kept in air tight cans or drums.] open air gradual disintegration occurs due to atmospheric moisture.

Calcium Carbide is not affected by the ordinary solvents but wh brought in contact with water vigorous decomposition ensues with tl evolution of Acetylene gas and a residue of pure slaked lime. The g and lime are formed in the proportions of 26 and 74 respectively l weight. A pound of chemically pure carbide would yield 5½ cub feet of gas. The commercial carbide yields from 4¼ to 5¼ cub feet of gas per pound. One pound of pure carbide would require .5 pounds of water for complete decomposition.

Calcium Carbide is packed in non-returnable sheet steel drums, co taining 100 pounds each. The sizes of carbide regularly carried i stock are as follows:

"Lump"—3½ inches by 2 inches. Large pieces.

"Egg"—2 inches by ½ inch. Medium pieces.

"Nut"—1¼ inches by ⅜ inch. For Carbide Feed Generators.

"Quarter"—¼ inch by 1/12 inch. For Carbide Feed Generators.

The carbide industry of this country is practically monopolized b the Union Carbide Sales Company of New York and Chicago. It i distributed by various depots over the country. The nearest depots fo this state are at Kansas City, Mo., and East St. Louis, Ill. The curren price of carbide at these depots is $3.75 per 100 pounds in less tha ton lots and $70.00 per ton in ton lots.

The railroad companies accord calcium carbide third rate classifi cation and carry it along with other freight.

ACETYLENE.

Acetylene is a colorless, tasteless gas having a characteristic pun gent odor. It is one of the so-called hydrocarbons, having a composi tion of 92.3 per cent carbon and 7.7 per cent hydrogen. This gas i

lighter than air, its comparative density being about .92. The corresponding figure for ordinary coal gas is .45.

Acetylene will not ignite of its own accord, but when set fire to in open air it burns with a white flame yielding carbon dioxide and water vapor. The high density and percentage of carbon in this gas is the source of its wonderful luminosity. When burned from a suitable burner which premixes the gas with a proper amount of air, an intensely brilliant white light results, the spectrum of which approaches very near that of sunlight itself. No smoke or odor is perceptible. This light on account of its whiteness is of great value for accurately distinguishing colors and is very desirable for domestic purposes, being when properly shaded, very easy on the eyes.

The combustion of Acetylene deprives the surrounding air of 2½ cubic feet of oxygen for every cubic foot of the gas burned, giving off in turn 2 cubic feet of carbon dioxide and 1 cubic foot of water vapor. For purposes of comparison we note that 1 cubic foot of coal gas requires 1 cubic foot of oxygen and throws off ¾ cubic foot of carbon dioxide. Now the ½ foot Acetylene burner giving 25 candle power consumes ½ cubic foot of gas per hour. The ordinary open coal gas burner giving from 18 to 25 candle power consumes 5 cubic feet of gas per hour. Thus we see that for equal illumination Acetylene impoverishes and pollutes the air only about one-fourth as much as coal gas. Now a coal oil lamp of the best kind will give about 25 candle power and consumes approximately one gallon of coal oil for twenty hours use. The oil lamp impoverishes and pollutes the surrounding air to a far greater extent than either of the above gases.

For equal candle power illumination Acetylene causes less heating of the surrounding air than coal gas and far less than the coal oil lamp.

Acetylene is considerably less poisonous than the coal gas which is ordinarily used for illumination. Fatal results from inhalation are not on record and it is said they could not possibly occur until the gas exists in the proportion of more than 20 per cent. The danger to be apprehended from this source is too remote for serious consideration. The steady escape of gas from an open half foot burner in an air-tight room 8 feet square and 8 feet high would produce a mixture of 5 per cent in 50 hours. The characteristic odor of the gas will attract attention to an open burner or a leak long before harm could result from same.

Contrary to the general concensus of opinion which seems to prevail, Acetylene is not a dangerous illuminant. However, this gas possesses in common with other illuminating gases the property of forming a violent explosive mixture with air. The ideal mixture would be one foot of gas to about 12½ feet of air. From this condition the mixture explodes with varying degrees of violence between the limits of 20 per cent of air to 4 per cent of air. Here again the odor of the

gas would be liable to attract attention to the vicinity of a leak or open burner long before a dangerous mixture could exist in a room.

It is impossible to obtain explosion or even ignition of a body of pure gas by the introduction therein of a lighted match or electric spark. However, Acetylene may be exploded by the detonation of a dynamite cap or other violent explosive in a body of the pure gas.

LIQUID ACETYLENE.

At a temperature of 68 degrees Fahrenheit and about 597 pounds per square inch pressure, Acetylene may be liquified. This liquid is of a violent explosive nature and does away with all thought of storing the gas by this means.

No one has ever succeeded in getting an explosion from Acetylene at a pressure under one atmosphere. Since the ordinary pressure of the gas under service is but a few ounces at most, it is evident that there is absolutely no danger to be apprehended from this source.

DISSOLVED ACETYLENE.

When Acetylene is compressed and forced into a tank filled with some porous material saturated with the liquid "Acetone," it seems to lose the explosive properties that it ordinarily possesses when under pressure. Acetone dissolves twenty-four times its own bulk of the gas at ordinary temperature and pressure and the quantity dissolved increases directly with the pressure applied. Now as the pressure is released the gas escapes and is delivered cool and dry to the burners.

Dissolved Acetylene finds its application with yachts, motor cars, railway headlights and railway car lighting. For ordinary house lighting it is entirely out of the question; acetylene can be provided for stationary purposes by generators so much more economically that Dissolved Acetylene finds no application here.

Acetylene is soluble in water to the extent of eleven volumes of gas to ten of water. But the solubility of gas in water is too limited to be put to any practical use. However it is of consequence for us to know about this, for the excessive use of water in a gas generating apparatus might cause considerable loss of gas.

ACETYLENE GENERATORS.

The function of an Acetylene generator is a comparatively simple one. It provides for the bringing together of the water and the carbide, washing and filtering the gas, storing it to a certain extent, and delivering it under a small pressure to the service pipe for distribution. Acetylene generators are divided into two general classes, Automatic and Non-Automatic. In the automatic machine the gas is generated as it is used, the quantity generated being automatically governed by the rate

of consumption. In the non-automatic machine a definite quantity of gas is generated at a fixed rate and stored. The former type is used for all small installations such as house lighting plants. The latter type is used for large plants, such as village lighting systems. In this discussion we are interested chiefly in the automatic generator as a private lighting plant for the country home.

The most important feature to be considered in the design of an acetylene generator is that of cool generation. When the carbide and water unite to form gas, violent chemical action occurs with the liberation of large quantities of heat. If this heat be localized, dangerous temperature rise is liable to occur. The carbide in such a type of generator would not give its full quota of gas and the burners would soon clog up due to its impure quality.

When water is fed into the carbide it is evident that there will be more or less localization of heat with consequent hot generation. Hence the most rational method would be to feed carbide in small well regulated quantities into a large body of water where the heat would be quickly transferred and dissipated. The water to carbide feed type of generator designated as the "water feed" generator is rapidly disappearing from the market and the carbide to water or "carbide feed" generator is now almost universally used.

The carbide feed generators are divided into the following classes by Mr. Einstein in the Acetylene Journal for September, 1907:

The "direct feed"—Feeding the carbide by gravity into the water by opening the feed valve which is operated directly by the gas holder bell.

The "indirect feed"—The gas holder bell operates a feeding mechanism which carries the carbide forward to the feed point where it falls into the water.

The "independent feed"—The feed valve is operated by a clockwork or motor mechanism controlled by gas holder bell.

The "indirect independent feed,"—A motor or clockwork controlled by gasholder bell operating a feed mechanism which carried the carbide forward to the feed point.

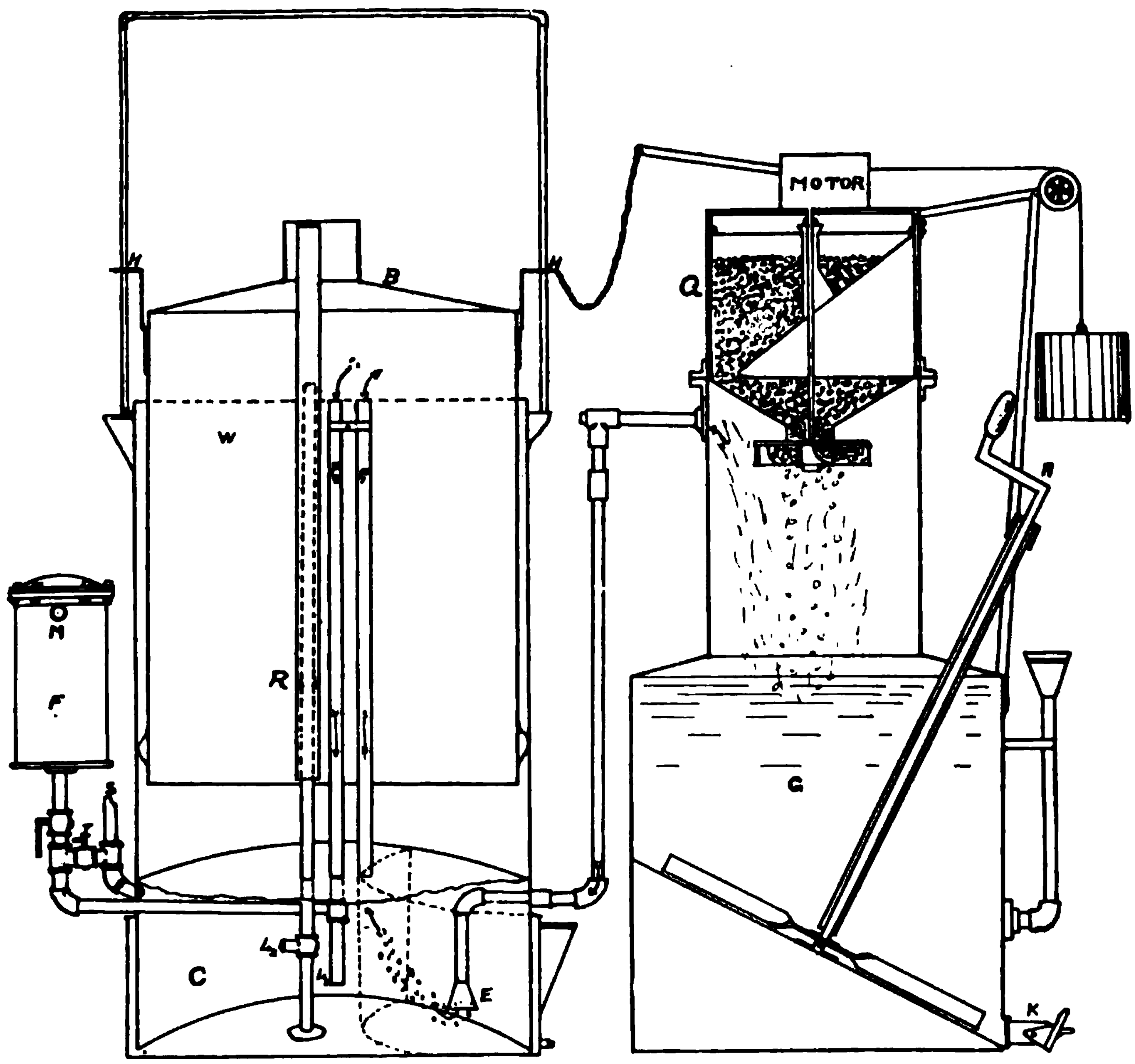
The indirect independent feed and the direct feed machines are shown in Figures 1 and 2 respectively.

The Acetylene gas machine consists of two essential parts. The generator proper and the gas holder, or gasometer as it is often called. The gasometer by the rise and fall of its gas bell regulates the quantity of gas generated and also serves as a pressure equalizer, supplying the gas to the mains at a constant uniform pressure.

A typical carbide feed machine is shown in Fig. 1. The carbide is fed from hopper Q into the body of water G. Gas is generated and passes out into the water seal E. This chamber is partially filled with water. From E the gas passes thru the pipe P_1, into the gasometer.

The gasometer bell is closed at the top and open at the bottom. It rests in the body of water whose surface is at W. As gas enters the bell rises, thus acting as a storage tank for the gas. The telescopic action of the bell is guided by the rods H. The gas bell supplies gas at a virtually constant pressure thru pipe P_2 and filter F to service main at M. When the bell rises to a certain height it stops the weight motor and hence carbide feed. When the bell drops below this point, carbide is again fed into the water until the bell rises above this point. The chamber C is of course filled with water to the same height as the water in E. Hence any undue

FIG. 1.



pressure in gas bell will cause gas to bubble through open connection at L_1 into chamber C. If the gas bell should accidently rise too high due to a fault in the mechanism or undue after generation, the gas will enter telescopic tube at R and escape through L_2 into C. The chamber C is connected with the open air by the escape pipe S. The by-pass valve I is used should it become necessary to empty gas bell for cleaning or repairs. The generator is cleaned by agitating the contents of G with the mixer A. The mixture of slaked lime and water is then drawn off from the sludge-cock K. The handle A is water sealed as shown to prevent the escape of gas around same.

In outlining the principles of this gas machine, we have brought out the important features of all high grade Acetylene generators They all accomplish the same results, embodying the same principles and safety

FIG. 2.

devices and differ mainly in methods of feeding carbide and mechanical details of construction.

In the water feed machine the water is slowly fed to the carbide. The carbide charge is divided in a series of separate compartments and the

water gradually feeds in a free flowing stream, thus flooding the carbide. Only one cell is flooded or in operation at a time. The flow of water is governed by the rise and fall of the gas bell. This machine tho an evolution of the water feed machines of bygone days, does not embody the features of rational generation as the carbide feed machine does, and hence would be less satisfactory for ordinary purposes. However this type of generator is perfectly safe and reliable and is especially adapted to localities where water is very scare, since merely enough water is used to completely decompose the carbide, while with the carbide feed machine about one gallon of water per pound of carbide is used.

Prof. George Gilbert Pond of Pennsylvania State College says that whatever the type may be, a good generator, such as can be recommended for household use, must be possessed of certain qualities which will be conceded by all:

(1) "It must allow no possibility of the existence of an explosive mixture in any of its parts at any time. The perfect machine must be so constructed that it shall be impossible at any time under any circumstances to blow it up. It must be 'fool proof.'"

(2) "It must insure cool generation."

(3) "It must be substantially constructed of good heavy metal which is not liable to rust and cause leakage and consequent dangerous gas mixtures."

(4) "It must be simple. The more complicated the machine, the sooner it will get out of order. Understand your generator. Beware of a generator whose interior is filled with pipes, tubes, valves, and diaphragms whose functions you do not perfectly understand. If a complicated mechanism is employed to perform what seems to you a simple duty, rely upon your common sense and judgment and look further until you find a perfectly simple but strong mechanism to perform the work automatically of making the gas. There are plenty of them and you can afford to meet the price of the machine which is least likely to call for repairs next season."

(5) "It should create no considerable pressure in any of its parts. More than a pound of pressure at any point may be a source of danger; more than a few ounces is wholly unnecessary and not to be tolerated."

(6) "It should be capable of being cleaned and recharged without the loss of gas into the room. In a good machine there will be no perceptible odor in its neighborhood."

(7) "It should require little attention. All machines have to be emptied and recharged periodically; but the more this process is simplified and the more quickly this can be accomplished the better."

(8) "It should be provided with a suitable indicator to designate how low the charge is in order that filling may be done in season and the house not plunged in darkness without notice."

(9) "It should completely use up the carbide, generating the maximum amount of gas."

There are plenty of good generators on the market. No less than 52 are approved by the National Board of Fire Underwriters up to date. For years the country was flooded with many weird devices of a worthless and even dangerous character simply because this field offered so many attractive possibilities to the amateur inventor. Happily these machines have been weeded out and improved until one need select only such machines as are passed upon and approved by the National Board of Fire Underwriters. We are appending the latest approved list of Acetylene Gas Machines. This list includes many excellent and seemingly perfect machines and all on it should be safe and reliable.

PLANNING OF LIGHTING SYSTEM.

When deciding on a lighting plant for the home we might well divide our procedure into several steps. The first and most important is to accurately determine the capacity or size of machine desired. Next we select a particular make of Generator. Third, we definitely decide on a location for same. Fourth, we work out the piping scheme for the house. Fifth, we select our fixtures.

CAPACITY OF GENERATOR.

It is important to select a machine of ample size to suit all present requirements and allow a liberal estimate for future outlets. It is far better to install a machine of slightly larger than required capacity, than to find out too late that we have skimped on our original estimate. The additional first cost of a larger machine is slight and the attention required will be less, since it will have a greater carbide capacity and consequently furnish gas from one charge for a longer period of time to the same number of outlets. The National Board of Fire Underwriters advise the following rules for determining the size of generator required:

(1) "For dwellings, and places where machines are used intermittently the generator should have a rated capacity, i. e., pounds of carbide at one charge, equal to the total number of burners installed."

(2) "For stores, opera houses, theatres, day run factories, and similar service, the rated capacity should be from 30 to 50 per cent in excess of the total number of burners installed."

(3) "For saloons and all night or continued service, the rated capacity should be from 100 to 200 per cent in excess of total number of burners installed."

"This rating is based on the so-called ½ foot burner giving a steady illumination of 25 candles and consuming ½ cubic feet of gas per hour. (Burners usually consume from 25 to 100 per cent more than their rated consumption of gas, depending largely upon the working pressure. The

so-called ½ foot burner when operated at pressures of from 2 to 2½ inches water column, is usually used with best economy.)" In addition to the ½ foot size of burner, there are the 1½ foot burner rated at 75 candle power, the 1 foot burner rated at 50 candle power, ¾ foot burner rated at 37 candle power, and the ¼ foot burner rated at 12 candle power. Two ½ foot burners with suitable shades will give plenty of light for the ordinary sized living room with light walls. A good rule to follow is to allow 2 square feet of floor area per candle power where brilliant illumination is desired. Three square feet per candle power will give good light under all conditions.

One ½ foot burner will be found ample for a bedroom unless a wall bracket is desired in addition. Be sure and allow lights for halls, porch, cellar, outhouses and barn.

If heating or cooking units are to be installed make allowances as follows:

Acetylene Range.—Each cooking burner consumes about 3 feet of gas per hour, the oven burner consumes about 5 cubic feet of gas per hour.

Hot Plates.—From 2 to 3 feet of gas per hour.

Small Bedroom Heaters.—About 2 ¾ cubic feet of gas per hour.

Now reducing everything to equivalent half foot burners and we are in a position to decide on the capacity of our proposed machine.

SELECTION OF GENERATOR.

Having a generator of definite capacity in mind, we are ready to proceed with the selection of our machine. We will in all probabilities settle on the carbide feed type since the small additional amount of water required would be an item in very few communities. If we have no stated preference for any particular make of machine, we had best write to a few representative firms given on the "Approved List" and state our case clearly and concisely. These firms will be glad to take the matter up with us, giving us detailed description of their apparatus with their cost data, advise us as to size, methods of installing and operating their particular machine, etc. Now in making our selection we should be guided by the requirements outlined by Prof. Pond and choose that machine which in our estimate conforms more nearly with these requirements.

A table of average specifications and cost worked out from leading makes of machines is appended.

LOCATION.

We must now decide on the location of our generator. It is preferably located in a special "generator house" built for this purpose, especially if the machine is of large capacity. Such a house should be provided with double walls, be well ventilated and dry, and must if neces-

sary be artificially heated in winter to prevent danger of freezing of water in generator. It is generally more convenient and inexpensive to locate the generator in the basement of an outhouse; or it may even be located in the basement of the main building if the company insuring property consents to same in writing on its policy and it is not prohibited by certain local authorities or boards. The machine must of course be of an approved make and there must be no open jet within ten feet of the machine and it must be placed at least fifteen feet from the furnace.

The machine must be so placed that the operating mechanism will have room for free and full play and can be adjusted *without the aid of artificial light.* It must not be subject to interference by children or meddlesome persons, and it may be well to enclose the machine by a slatted partition for this reason. The generator should be placed on a strong, level, foundation. If this foundation is of wood it should consist of heavy timbers located in a dry place and open to the circulation of air as shown in Fig. 2.

PIPING.

The generator should be provided with an escape or relief pipe not less than ¾ inch internal diameter. This pipe will be installed without a trap so that any condensation will drain back to generator. It must be carried outside the building and terminate in a properly constructed hood or return bend looking down about 12 feet from the ground. The machine should discharge into a suitable open receptacle for the removal of sludge and water. This receptacle is preferably connected with a drain emptying into a sludge pit or a sewer and much labor in carrying out the lime water with pails will be saved thereby. If the premises are supplied with running water, it will be found convenient to have a tap near the generator for supplying the same with water when it is to be recharged.

If the building is already piped for gas it will only be necessary to connect service pipe in basement with the generator. If, as is usually the case, the building must be specially piped, the schedule for pipe sizes should conform to that commonly used for Acetylene gas, but in no case should the feeder pipes be smaller than ⅜ inch. A schedule of pipe sizes is appended.

The piping work should preferably be done by a regular plumber or gas-fitter. If the services of a plumber are not obtainable, the work can be done by any skillful mechanic such as may usually be found in the small towns. A good man and his helper will be able to completely pipe an average residence in three days time. If the house is an old one, it may take a little longer to make a good job of concealed work. Competent plumbers will usually agree to pipe a house complete, furnishing all material for from 10 to 15 cents per running foot.

The service connection with the generator is made with a pipe of the same size which in turn leads to a riser of the same size, running up thru the building as near the center as possible. The feeders run out from the riser at each floor and these in turn branch off to the fixtures. The feeders and branches should be of ample size as determined by the piping schedule appended.

Black iron pipe should be used with malleable galvanized fittings. Connections from generator to service pipe should be made with right and left thread nipples, or long thread nipples with lock nuts. Unions should never be used for gas fitting. All piping should be pitched to drain back into the generator. If low points occur thru necessity, they must be drained thru tees into drip cups permanently closed with screw cap plugs. Never use pet cocks. Apply a little white lead to all threads before coupling up to insure gas-tight joints. The piping must be rigidly supported by hooks and straps. Outlets for brackets or drops must be secured by straps or flanges, which are nailed or screwed to the woodwork. Always use fittings in making turns; do not bend pipe. Do not use unions, but instead use long thread, or right and left hand couplings. Long runs of approximately horizontal pipe must be firmly supported at proper intervals to prevent sagging. All longitudinal outlet-pipes must be taken from the sides or top of running lines, never from below. All ceiling outlets must project not more than 2 inches nor less than ⅝ inch, and must be firmly secured and plumb. Side wall outlets must be firmly secured and must not project more than ⅝ inch and must be at right angles to the wall. Where pipes pass thru masonry walls they must be incased. Pipes must be run and covered so as to be readily accessible. Do not run at bottom of floor beams which are to be lathed and plastered. They must be securely attached to the top of the beams which should be notched as shallow as possible. Where pipes are paralleled to beams, they must be supported by strips nailed between the two beams, about four feet apart. Floor boards over pipes should be fastened down by screws, so that they can be readily removed.

FIXTURES.

In the matter of fixtures one is guided entirely by his own taste and by the amount of money he is willing to appropriate for the purpose. Fixtures may be procured in a variety of styles with from 1 to 4 lights each. The firm selling the generator will furnish a catalog of acetylene gas fixtures or refer to dealers who handle them.

Inexpensive fixtures may be made by building them up from common ½″ or ⅜″ black iron pipe and painting or gilding to suit. Such fixtures are commonly used for store lighting.

The fixtures may be fitted with any of the standard burners already referred to. The actual size of flame produced by these burners is shown in Fig. 3. The appearance and actual size of the ordinary acetylene burner is shown in Fig. 4.

FIG. 3.

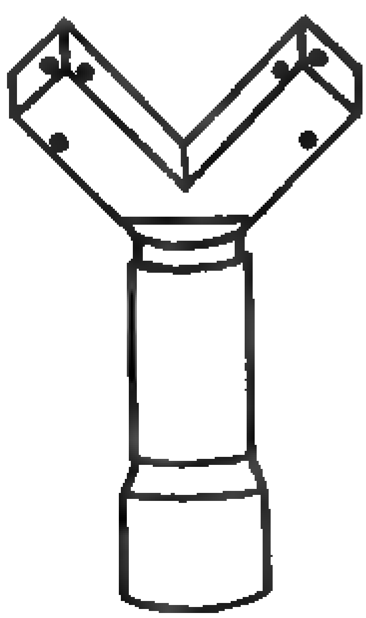
1 cu. ft.	¾ cu. ft.	½ cu. ft.	¼ cu. ft.
50 C. P.	37 C. P.	25 C. P.	12 C. P.

Actual Size and Appearance of Acetylene Flames.

For residence lighting the fixtures should hang about 6 1-3 feet from the floor. For bedrooms they may be hung slightly lower however, and wall brackets should be placed about 5 ½ feet from the floor.

When ordering fixtures be sure and measure the ceiling heights and state the length of each fixture in the order.

FIG. 4.



Acetylene Burner.
(Actual size.)

It is advisable to use globes similar to the Holophane Glass Globes for use with all fixture and bracket lights where good illumination is desired. These are glass globes or shades constructed along well known optical principles so that they diffuse the light by cutting down the intense glare, with practically no loss by absorbtion. At the same time they

increase the useful light below the horizontal. Where reading is to be done it is imperative to have good shades since without these there will be very poor illumination directly below the light. The acetylene flame due to its high intrinsic brillancy will dazzle the eye when looked at directly. The light will also cast very sharp shadows due to its small size. All of this will be remedied by the proper use of diffusing globes or shades.

These globes are made in three classes. "Class A"—adapted for use over dining room and library tables, desks, counters, etc., where a strong light is wanted directly downward. "Class B"—for general illumination such as for lighting parlors, bed rooms, stores, etc. "Class C"—designed to give maximum light just below the horizontal, and therefore adapted for use in low chandeliers, wall brackets, etc., where it is desired to light a large area. Especially recommended for illuminating long hallways as corridors, large rooms, etc.

ACCESSORIES.

Electric Ignition. With a special style of automatic burner and an electric ignition outfit, one can have light by the simple pressure of a button on the wall. The battery and coil are concealed in any convenient nearby closet or in the basement. Such an outfit costs in the neighborhood of twelve dollars. It is very convenient and safe for barns where an enclosed light must be used and matches are dangerous. The same sort of an appliance with a chain pull igniter instead of the push button variety may be had for about six dollars. One battery and coil may be used in connection with any number of burners.

HEATERS AND COOKERS.

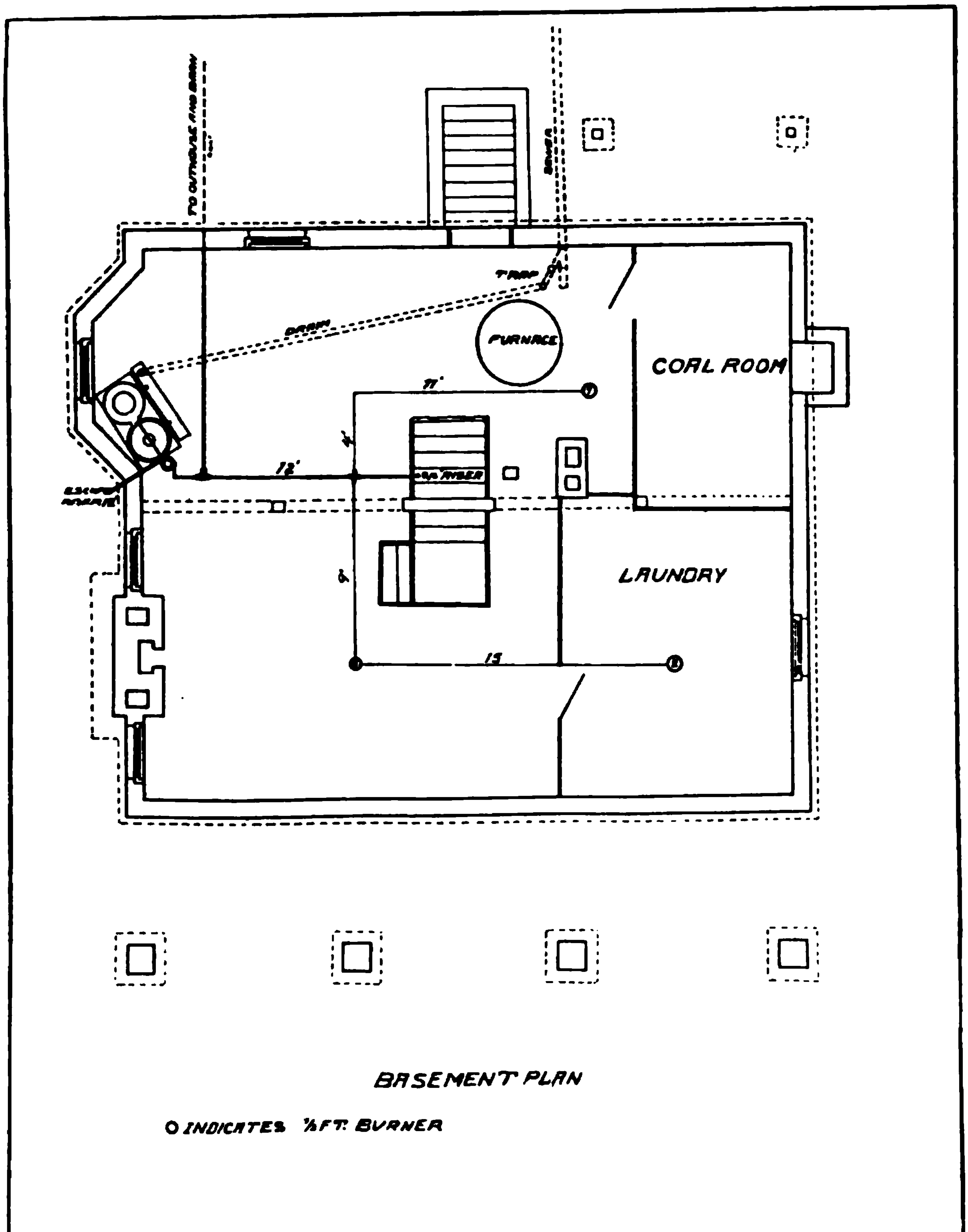
The heating value of Acetylene is about two and one-half times that for ordinary coal gas. With carbide at its present price this does not make the cost of heating and cooking by acetylene at all prohibitive. This would certainly be a useful and convenient adjunct to lighting by acetylene, as cookers and heaters of numerous sizes and varieties designed especially for use with Acetylene gas are now on the market. Acetylene Ranges of the four burner style with a large oven may be purchased at a surprisingly low figure. The consumption of gas per burner is three feet per hour. The oven consumes about five feet per hour, and it is said will bake biscuits in ten minutes. A variety of cookers and hot plates are available. Chafing dish heaters may be had consuming 1 ½ feet of gas per hour. Bath and bed room heaters are also available.

The portable heaters may be connected with a nearby jet with a rubber tubing. If a gas range or cooker is installed, a permanent connection should be made with the generator by a separate lead.

DESIGN OF A TYPICAL INSTALLATION.

We will now go into the details of a typical installation for a country home whose plans are shown in Figures 5, 6, and 7. On the first floor are Dining and Living Rooms, Parlor, Reception Hall, Pantry, and large front porch. On the second floor are three Bedrooms, a Store Room,

FIG. 5.



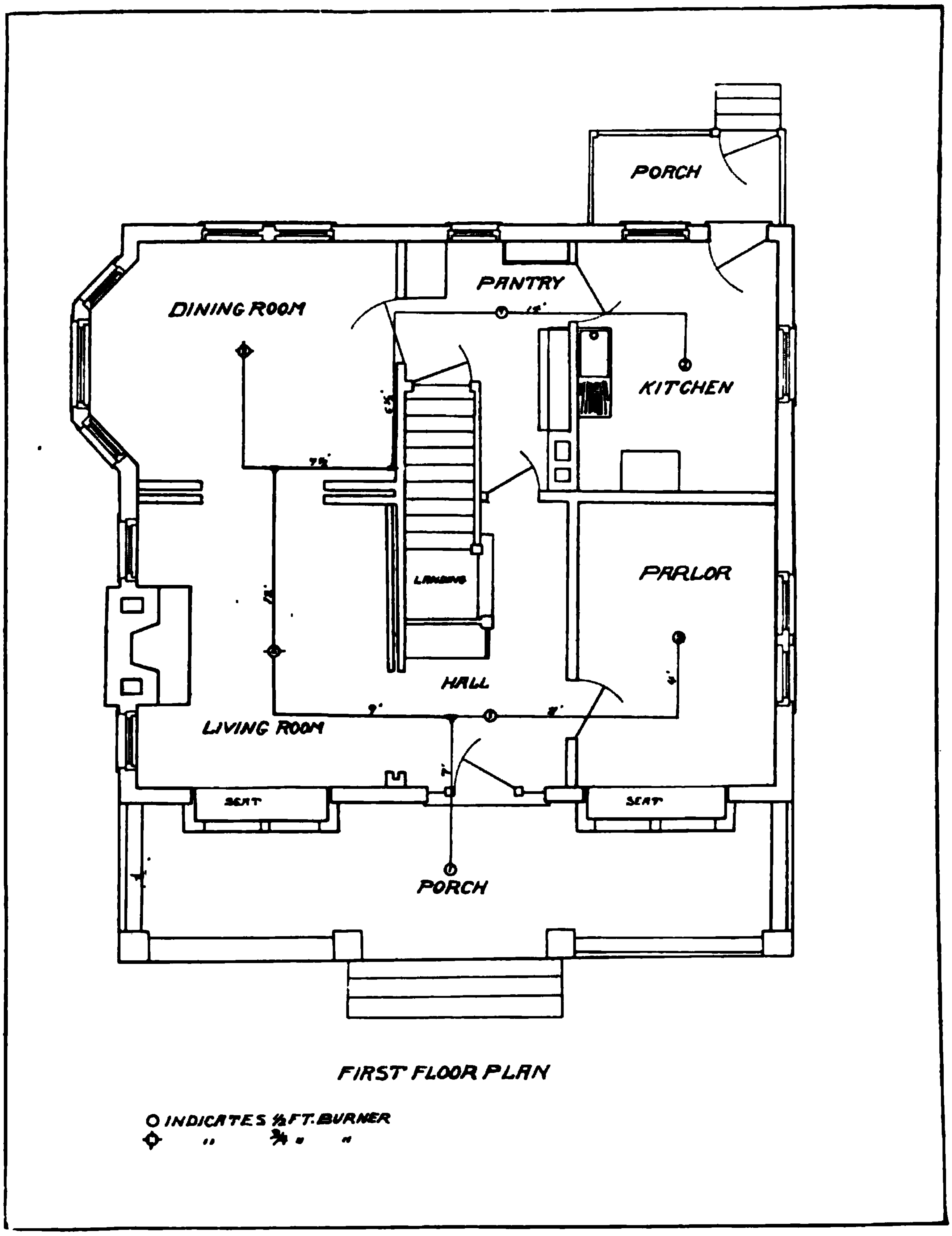
Hall and Bath Room. In the basement there is a Furnace Room, Fuel Room, Laundry and Store Room.

LIGHTING ARRANGEMENT.

Living Room.—This room should be well lighted, since more time is spent here by the family than in any other room in the house. The light should be well distributed below the horizontals to admit of several per-

sons reading in the room at the same time. Accordingly we select a two-light fixture with ¾-ft. burners and Holophane Shades, Class B. This will give a very brilliant lighting below the horizontal and also good general illumination over walls and ceiling.*

FIG. 6.



Dining Room.—Brilliant illumination is desired over the table. We will select a two-light fixture hung in the center of the room with ¾-ft. burners and Class A Holophane Globes.

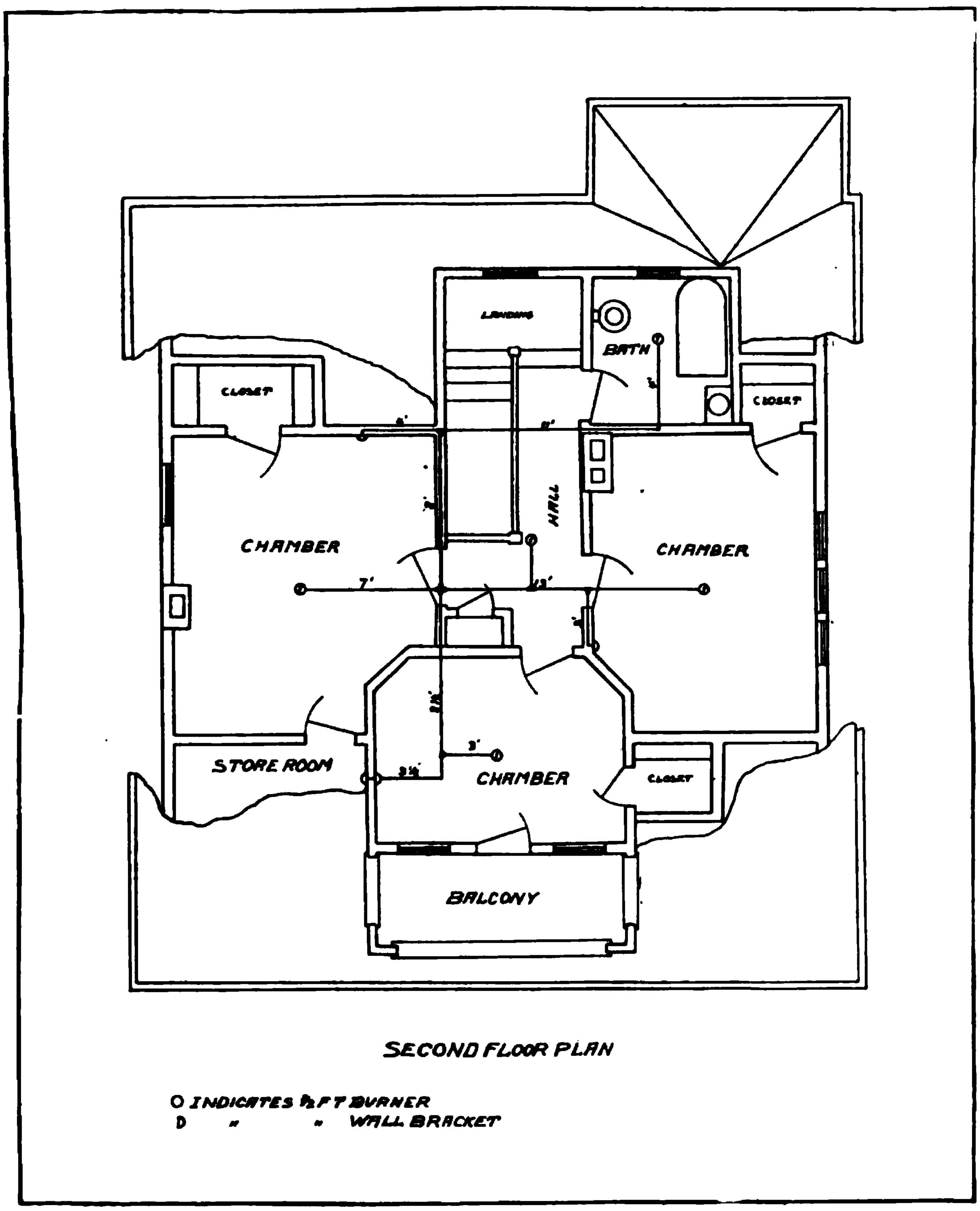
Kitchen.—Here the housewife spends a great part of her time. The operations carried on here are of vital interest and importance to the en-

*All fixtures will be placed 6 ft. 4 in. off the floor unless otherwise specified.

tire family. It should be well lighted though not so brilliantly as the dining room. A simple two-light fixture with ½ ft. burners and Class B Holophane Globes will suffice here.

Parlor.—A two-light fixture with ½ ft. burners will be ample for this room. We may use Holophane Globes of Class B type, or select globes of a more elaborate or tasteful design to harmonize with the general scheme of decorations in the room.

FIG. 7.



Pantry and Bath Room.—One-light fixtures with ½ ft. burners and Class B Shades.

Halls.—One-light fixtures with ½ ft. burners and Class C shades should be used for the halls.

Front Porch.—A regular porch light fixture with a ½ ft. burner and suitable globe and canopy to protect it from wind will be used here.

Bedrooms.—These chambers are each fitted with one-light ceiling fixtures with ½ ft. burners and Class B globes. These ceiling fixtures are hung about 6 ft. off the floor. "Two swing" brackets with ½ ft. burners and Class C globes are placed on wall in each room so as to give a good light near mirror to dress by. These brackets should be placed about 5 ½ feet off the floor.

Basement.—An open ½ ft. burner is placed near the furnace. One is also placed in the store room. A short two-light bronze spread equipped with ½ ft. burners is placed in the laundry. It will be noticed that light is placed in the vicinity of the generator.

Outhouse and Barn.—The outhouse is equipped with two ½ ft. wall bracket burners. The area way of the barn is lighted by an enclosed ¾ ft. burner equipped with an electric chain pull igniter.

CAPACITY OF GENERATOR.

Adding up all of our outlets we find that we have twenty-two ½-ft. and five ¾ ft. burners. The equivalent is about thirty ½ ft. burners. We will select a "size 50" or 50 light generator, since this will allow for any under-rating of the burners and also allow liberally for future extension.

INSTALLATION AND PIPING.

We will assume that the company insuring the property consents to our placing the generator in the basement. We will thus be saved the added expense of an outhouse which would have to be specially heated in the winter. The machine will be placed about 20 feet from the furnace near the basement window. A nearby window is desirable so that all cleaning and charging may be done without the aid of artificial light. A wooden foundation is made for the generator as shown in Fig. 2. A trough of heavy galvanized iron about 8" x 8" x 26" is placed in front of the machine and connected with a 2" drain which in turn leads to the sewer thru a suitable trap. This trough and drain will merely be an added convenience and may be dispensed with if it is proposed to use the sludge for some practical purpose when it is emptied from the machine. However, if drain is to be used never connect directly with a sewer, but let generator first discharge into a suitable open receptacle which may in turn have such connection.

A 1 inch escape pipe is led outside and terminates in a weather bend about 12 feet from the ground. A ¾ inch service pipe connects with generator thru a long thread nipple with lock nuts. The service pipe is led to a ¾ inch riser which reaches the ceiling of the second floor. Half inch feeder pipes are led off from the riser at each floor as shown. These feeders in turn branch off into ⅜ inch pipes which lead to the outlets. The reductions of ½ inch to ⅜ inch are clearly indicated on the plans which show piping arrangement, Fig. 5-6-7.

A ¾ inch galvanized pipe is laid underground to supply two ½ ft. burners in an outhouse and a ¾ foot burner in the barn. The total length of this outside piping system is 200 feet.

ESTIMATED FIRST COST OF INSTALLATION.

Piping System.	
18 feet of 1 inch pipe, 235 feet of ¾ inch pipe, 40 feet of ½ inch pipe, 177 feet of ⅜ inch pipe	$ 22 00
Pipe Fittings	5 00
Labor, 1 man at $3.50 per da. for 4 days	14 00
Labor, 1 man at $1.50 per da. for 4 days	6 00
Total Cost of Piping	$ 47 00
Drain.	
Galvanized iron trough	$ 2 00
20 feet of 2 inch pipe	2 60
Fittings, trap, etc.	3 00
Labor	2 00
Total Cost for Drain	$ 9 60
Foundation for Generator.	
Wood open work Foundation	$ 1 00
Fixtures.	
Dining Room, Living Room, Parlor: Two-light, polished brass finish, turned brass fittings	$ 16 50
Pantry: One light bronze	1 00
Kitchen: Two light bronze	2 00
Hall: One light polished brass	3 50
Porch: One light crystal globe, canopy windguard	5 50
Bed-rooms: Three, one light polished brass	6 00
Bed-rooms: Three, Brackets, 2 swing, polished brass	4 50
Bath-room: One light, polished brass	2 00
Hall Upstairs: One light, polished brass	2 00
Basement: Two one light bronze	2 00
Laundry: Two one light bronze	2 00
Outhouse: Two bronze brackets	1 40
Barn: Enclosed globe with chain pull igniter and accessories	13 00
Total	$ 61 40
Discount at 20 per cent	12 28
Actual Cost	49 12

2 Dozen Holophane Globes	16 00
2 Dozen 2 ¼ inch Holders	3 00
Total	19 00
Discount at 33 1-3 per cent	6 32
Actual Cost	12 68
2 ½ Dozen Acetylene Burners	6 00
50 Light Generator	158 00
Cost of Installation Complete	$283 40

Allowance for Freight and incidentals will bring this figure to $290.00.

TOTAL ANNUAL COST.

The actual cost of Acetylene at the rate of ½ foot of gas per hour with carbide giving 4 ½ feet of gas per pound and costing $4.00 per 100 pounds, would be ½ cent per hour. This would be the cost of operation for a burner consuming ½ foot of gas per hour. However, the total annual cost based on such a figure as this would be of little value since no allowance has been made for fixed charges. To estimate these we assume a 5 per cent interest rate, and a 4 per cent rate of depreciation on the generator, (the life of the generator is rather uncertain since it depends materially on its location and the attention it receives, such as thoroughly cleaning and painting it about once a year), and 2 per cent on the piping and fixtures. We will allow 1 ½ per cent for taxes and repairs. Now in order to know the amount of carbide which would be used per year, we will have to approximate the gas consumption of our lighting arrangement. The gas used per day will of course vary with the season, being considerably higher during the winter days than during the summer. A careful study of the number of hours each burner is likely to be used will give an average gas consumption of 12 cubic feet per day for the year round. Assuming our carbide as giving an average yield of 4 ½ cubic feet of gas per pound, we would use annually 975 pounds. The generator would need recharging on the average every 18 days. Now our total yearly cost will be:

Carbide: 975 pounds at $4.00 per 100 pounds	$ 39 00
Interest on $290.00 at 5 per cent	14 50
Depreciation on generator at 4 per cent	6 32
Depreciation on piping and fixtures at 2 per cent	2 64
Taxes and repairs at 1 ½ per cent	4 35
Total Yearly Cost	$ 66 81

This is about $2.20 per equivalent half foot burner installed.

A CHEAPER INSTALLATION.

In making the above estimates liberal allowances have been made and the design is perhaps more elaborate than desired for the average country home.

We may reduce the cost of the above installation materially as follows: Omit the drain in cellar and arrange to carry out the sludge in buckets or pump it out with a small pump and hose attachment which is made for that purpose. Omit light in barn and on the porch. Bronze instead of polished brass fixtures in bed rooms. Using a 35 light generator instead of the 50 light machine will reduce the cost by $23.00 alone. The total first cost of this installation would now be in the neighborhood of $225.00.

By turning out lights when not needed the carbide consumption for such an installation may be reduced to 650 pounds per annum.

The total annual cost will now be:

Interest on $225.00 at 5 per cent	$ 11 25
Depreciation, Repairs, Taxes	10 50
Carbide: 650 Pounds at $4.00 per 100 pounds	26 00
Total Yearly Cost	$ 47 75

These figures it will be understood are merely estimates made to cover the average case and will vary for different localities and with the extent of the installation. However, they will serve as a guide to those interested in applying them to their individual proposed installations.

CARE OF APPARATUS.

Rules and requirements of the National Board of Fire Underwriters for the construction, installation and use of Acetylene Gas machines and for the storage of Calcium Carbide, may be obtained from your insurance agent or by writing to Secretary's office, National Board of Fire Underwriters, No. 207 East Ohio Street, Chicago, Ill.

Complete directions for operation and care of apparatus will accompany the generator. However, we deem it advisable to point out some of the more important points to be considered in general where using any Acetylene Gas Machine.

Always recharge generator before carbide is entirely consumed, and observe a regular time during daylight hours only for attending to and recharging the apparatus. The sludge should be emptied from generator and it should be thoroughly flushed, then filled with clean pure water *each* time the carbide hopper is recharged.

The semi-liquid residue drawn from the generator may be used for white washing, as a fertilizer, insecticide, and disinfectant. The lime will make mortar which will set quickly and hard.

It is often convenient and inexpensive to let the drain from generator empty into a sludge pit where the lime will accumulate and can subsequently be used.

The water in the gas holder should be drained off once or twice a year and the holder thoroughly cleaned. The felt in the filter will need occasional renewing. This is easily observed by the dimming of lights when all are all turned on, due to the pressure of gas falling below normal in passing the felt. Always keep the tanks and seals filled with clean water.

When starting up a new installation open all burners till gas has forced the air out of the pipes before attempting to light burners.

Never test the generator or piping for leaks with a flame and never apply a flame to an outlet from which the burner has been removed.

Never use a lighted match, lamp, candle or lantern near the machine.

Never pack or ram the carbide in the hopper and use only such size of carbide as the directions call for.

If the generator is installed in a separate generator house, this house should be thoroughly ventilated and any artificial heating necessary to prevent freezing shall be done by steam or hot water systems.

STORAGE OF CALCIUM CARBIDE.

Calcium Carbide in quantities not to exceed 600 pounds may be stored when contained in drums not exceeding 100 pounds each, inside insured property, provided the place of storage is dry, weatherproof and well ventilated and also provided that all but one of the packages shall be sealed until the unsealed can has been completely used up.

In excess of 600 pounds, packages must be stored above ground in detached buildings used exclusively for this purpose, being dry, well ventilated and weatherproof.

VILLAGE PLANTS.

Lighting by Acetylene is not necessarily limited to residences or single buildings. Plants are being annually installed of sufficient size to illuminate towns of from 400 to 3,000 inhabitants. This furnishes a cheap, effective, and very satisfactory method of lighting small towns where coal gas plants would be failures and electric plants doubtful propositions.

The operating expense of a village plant is very low, since the services of but one man are required about one or two hours per day in attending and recharging the generator. The rest of the time the generator house is locked up and the generator takes care of itself.

Such a plant as we have already mentioned, is equipped with a non-automatic generator and a gas holder of sufficient capacity to contain at least four cubic feet of gas per ½ foot burner of the rating.

The carbide is fed into the water by hand or by a small water motor so that a slow and steady feed is assured. It is customary to generate enough gas at one time to last at least over a single night and often for several nights. Ample storage is desired so as to avoid the possibility of the gas supply ever failing and being turned on again while the burners are still open.

The station apparatus consists of a generator which is equipped with a cast iron filter, seal pot and suitable feeding device. Also, a station meter which is of sufficient capacity to measure all gas supplied from gas holder to the mains, a heating apparatus installed in a separate room and of sufficient size to keep the generator room at 50 degrees Fahrenheit in zero weather and a residuum drain of 6 inch vitrified terra cotta pipe connecting discharge gate of generator with an outside pit. The water supply is furnished by a standard pressure water system for supplying all water necessary for operation of plant, including the driving of the water motor such as is used for operating the feeding device. This water supply may be furnished by an elevated tank supplied by a pump and gasoline engine or windmill.

The gas holder is constructed in accordance with specifications furnished by the firm selling the generator. All mains and supply pipes are also installed in accordance with these specifications.

The price on a complete station equipment made to us by a prominent manufacturer of a non-automatic central station generator was $2500.00. The plant has a capacity of 1,000 cubic feet of gas per hour, and the gas holder has a capacity of 1500 cubic feet. A larger generator having a capacity of 2500 cubic feet of gas per hour and a gas holder of 3,000 cubic feet capacity, would cost about $3300.00. These prices include hot water heating plant installed, station meter, etc. The smaller size would be ample for a town of 1500 inhabitants or less. The larger size for 3000 inhabitants or less.

The cost of installing, mains, etc., will of course depend entirely on local conditions. However, the first cost of a municipal Acetylene lighting plant for a small town will be less than any other kind of lighting system. The cost of operation will certainly be much lower.

Small towns which have heretofore been in darkness simply due to the fact that a gas or electric plant could not be made to pay, may be beautifully and economically lighted by Acetylene.

We have in mind a small town in the State of Minnesota of about 500 inhabitants. They have a municipal Acetylene lighting plant which has been giving satisfactory service for eleven years. The gas is metered to the consumers at a rate of $1.25 per 100 cubic feet. The village allows a flat rate of $2.00 per month each for the town street lamps. This plant has a capacity of 1000 cubic feet of gas at a charge and requires the attention of one man a half hour each day. The first cost of this plant was $3500.00 as installed eleven years ago.

A pressure equivalent to a 4 ½ inch water column is maintained on the gas in the mains. This rather high pressure is necessary to force the gas in sufficient quantities to the ends of those service pipes which extend considerable distance from the plant.

The Union Carbide Company makes a rate of $60.00 per ton to municipal plants.

APPENDIX

RESULTS OF TESTS.

We conducted a series of tests in our laboratory in order to observe the actual consumption of gas for various rated burners and also to determine the cubic feet of gas available per pound of carbide under service conditions.

The generator used for the test was a 35 light carbide feed machine which was loaned to us by the Eagle Generator Company of St. Louis, Missouri.

The arrangement of generator, meters and burners for the test is shown in Fig. 8.

A Junker's Wet Meter was used for measuring the gas consumption of the burners per hour. A Maryland 3 light meter was also connected in the service line and carefully callibrated to measure the total quantity of gas used from a charge of carbide.

A pressure equivalent to a 2½ inch water column was maintained on the gas with an average temperature of 70 degrees Fahrenheit thruout the test on the burners.

We found that the ½ foot burners were but very slightly underated but that the larger sizes of Eagle burners seemed to be somewhat overrated. The results were as follows:

Eagle Burners.

Rating of Burner in cubic feet per hour.	Actual consumption cubic feet per hour.
1½	1.04
1	.785
¾	.584
½	.537
¼	.360

Colts Von Schwarz Perfection Burners:

1	1.01
¾	.811
½	.524
¼	.35

These figures were averaged from four runs on two burners of each size.

FIG. 8.

35 Light Carbide Feed Generator Arranged for Test.

Carbide from two different drums was tested. The contents of the first drum was very dusty and a strong odor of Acetylene prevailed when the drum was opened, indicating a slightly air-slaked condition. The average gas yield from carbide of this drum was 4.1 cubic feet per pound. Carbide tested from the second drum yielded 4.67 cubic feet of gas per pound. These are the actual figures which would be obtained under service conditions, as the usual procedure of expelling air from the generator was gone thru when starting up, and the gas was burned from a bank of burners several hours each day until the charge was exhausted.

APPROXIMATE DIMENSIONS AND COST OF AUTOMATIC ACETYLENE GENERATORS.

Rating—No. ½ Foot Lights.	Carbide Capacity—Pounds.	Height Required—Inches.	Floor Space Required—Inches.	Width of Door Required—Inches.	Service Pipe—Inches.	Weight—Gross—Pounds.	Price—Dollars.
20	20						100
25	25	75	24x40	22	½	250	120
30	30						135
35	35	80	27x58	25	¾-1	425	150
40	40						160
50	50	86	28x60	26	¾-1	500	175
75	75						250
100	100	92	34x68	30	1-1 ½	600	300
150	150						400
200	200	116	48x75	38	1 ½-2	1200	550
300	300						750
500	500	120	75x130	48	2	2500	1050
1000	1000						1650

Note:—The above are list prices and are usually subject to 10 per cent. or more discount.

PIPING SCHEDULE FOR ACETYLENE GAS.

No. ½ ft. Burners.	DISTANCE IN FEET AND SIZE OF PIPE REQUIRED.													
	10	20	30	40	50	60	75	100	125	150	200	300	400	500
10	3/8	3/8	3/8	3/8	3/8	3/8	3/8	1/2	1/2	1/2	1/2	3/4	3/4	3/4
20	3/8	3/8	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4	3/4	3/4
30	1/2	1/2	1/2	1/2	1/2	3/4	3/4	3/4	3/4	3/4	3/4	3/4	1/4	1
40	1/2	1/2	1/2	1/2	3/4	3/4	3/4	3/4	3/4	3/8	3/4	1	1	1
50	1/2	1/2	3/4	3/4	3/4	3/4	3/4	3/4	3/4	1	1	1	1	1
60	1/2	1/2	3/4	3/4	3/4	3/4	3/4	3/4	1	1	1	1	1	1
75	1/2	3/4	3/4	3/4	3/4	1	1	1	1	1	1	1	1 1/4	1 1/4
100	3/4	3/4	3/4	3/4	1	1	1	1	1	1	1	1 1/4	1 1/4	1 1/4
150	3/4	3/4	1	1	1	1	1	1	1	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2
200	3/4	1	1	1	1	1	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	1 1/2	2
250	1	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2
300	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	1 1/2	2	2	2
400	1	1 1/4	1 1/4	1 1/4	1 1/2	1 1/4	1 1/2	1 1/2	1 1/2	2	2	2	2	2 1/2
500	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2	2	2	2	2	2	2	2 1/2	2 1/2

LIST OF ACETYLENE GAS MACHINES

which have been examined under the Rules and Requirements of

THE NATIONAL BOARD OF FIRE UNDERWRITERS

By Its Committee of Consulting Engineers

and which may be permitted for the uses specified when installed according to requirements if not in violation of any state law or local ordinance, and

IF THE COMPANY INSURING THE PROPERTY CONSENTS TO THE SAME IN WRITING ON ITS POLICY.

To secure the largest measure of safety to life and property, Acetylene Gas Machines must be installed outside of buildings, and the National Board Rules strictly observed.

It should be noted that the installation of acetylene gas machines inside of buildings is prohibited in certain districts by local authorities and local boards.

The following named Acetylene Generators made by the persons and firms whose names are given have been examined and tested under the direction of this Committee, the factory practices used by these concerns are inspected from time to time and the manufacturers are under agreement to furnish for sale under these names only devices which are similar in all respects to samples and specifications on file at the Underwriters' Laboratories.

They are safeguarded to as great an extent as it is possible to safeguard appliances of this character.

Be sure that the trade-name, and the name of the manufacturer, as given in the list, are marked on the machine, and that the generator purchased is of the type manufactured since the date of the examination

Follow carefully the Rules for Proper Installation, Care and Maintenance of Acetylene Generators, a copy of which may be obtained from your insurance agent.

CLASS A.

STATIONARY APPARATUS FOR ISOLATED INSTALLATIONS.

Acetylene Report No.	Name of Machine	Manufactured by	Manufactured at	Date of Original Exam.		Date of Last Re-exam.	
198	Abner Giant	The Krein Mfg Co	Wapakoneta, Ohio	July	1909	June	1908
260	Abner, Jr	The Krein Mfg Co.	Wapakoneta, Ohio	March	1901	Feb.	1909
372	A Free Light	[illegible]	[illegible] Mo.	April	1905	Sept.	1908
261	Aurora	[illegible]	[illegible] Tenn.	July	1901	May	1908
473	Beloit	[illegible]	[illegible]	June	1909	....	
343	Ben Hur	[illegible]	[illegible] Ind.	Jan.	1902	April	1909
482	Birch	[illegible] Ill.	[illegible]	Sept.	1909	....	
438	Brauer	[illegible]	[illegible] Iowa	Jan.	1907	Aug.	1909
40	Buckeye	[illegible] o.	Freeport, Ohio	April	1898	May	1908
419	Buzzell	Robinson & Love	Sycamore, Ill	March	1906	Sept.	1909
373	Carter	Niagara Falls Acetylene Gas Machine Co	[illegible] Y.	Jan.	1903	July	1909
216	C K Sober	C K. Sober	[illegible]	Nov.	1899	Feb.	1909
346	Colt, Model N.	J B Colt Co.	[illegible]	April	1902	Sept.	1909
420	Colt, Model O	J B Colt Co	[illegible]	Nov.	1903	Sept.	1909
434	Comet	Comet Acetylene Apparatus Co.	[illegible]	Aug.	1906	Aug.	1907
211	Golden's	U S Acetylene Co	[illegible]	June	1907	Feb.	1909
337	Davis Model B	Davis Acetylene Co.	[illegible]	Dec.	1901	March	1909
283	Davis Model C.	Davis Acetylene Co.	[illegible]	April	1903	March	1909
30	Daylight	Daylight Acetylene Gas Co	[illegible]	March	1898	Aug.	1909
450	Daytona	St Clair Mfg Co.	[illegible]	Sept.	1907	Oct.	1909
1	Eagle	Eagle Generator Co., St. Louis, Mo	[illegible]	June	1897	March	1908
265	Gate City	Visser & Brown	[illegible]	April	1901	Aug.	1909
391	General	Commercial Acetylene Co	[illegible] f.	Sept.	1908	April	1909
369	Grand Rapids	G F Owen	[illegible] ch.	Jan.	1903	Feb.	1909
418	Hays	J T Hays & Son	Emmitsburg, Md.	Jan.	1907	Feb.	1909
448	Hercules	Hercules Mfg. Co.	Chattanooga, Tenn.	Jan.	1907	May	1908
365	Higgs	Davis Acetylene Co., for Home Carbide Co., Chicago Ill	Elkhart, Ind	Jan.	1903	March	1909
440	Holm	Springfield Acetylene Generator Co.	Springfield, Ohio.	Dec.	1906	Feb.	1909
482	Hunter	Hunter's Gas Co Chicago, Ill	Elkhart, Ind	Sept.	1909	....	
240	Ideal Epworth Type D	Ideal Epworth Acetylene Co.	Waterloo, Iowa	Sept.	1900	Sept.	1909
241	Ideal Epworth, Type D	Ideal Epworth Acetylene Co.	Johnstown, Pa	March	1907	Oct.	1909
466	Illinois	Monmouth Acetylene Electric Mfg. Co	Monmouth Ill.	Nov.	1905	March	1909
328	King	C A. King	Norwich, N. Y.	Oct.	1902	Jan.	1908
71	Laun	Laun Bros.	Chicago, Ill	Aug.	1898	Feb.	1908
464	Model	National Welding & Mfg Co	Buffalo, N Y	May	1908	Sept.	1909
273	Monarch Carbide Feed	Monarch Acetylene Gas Co.	Buffalo N. Y.	July	1904	Sept.	1909
410	Night Commander	United States Standard Co.	Voorheesville, N. Y.	Aug.	1905	Nov.	1907
282	Orion	Matteson Acetylene Gas Generator Co., successors to Boonville Acetylene Generator Co., Boonville, N Y.	Pulaski, N. Y	Oct.	1904	Jan.	1908
340	Phelps Carbide Feed	The New England Mfg. Co., Chicago, Ill	Elkhart, Ind.	April	1903	Aug	1909
468	Phelps Limited Feed	The New England Mfg Co., Chicago, Ill.	Elkhart, Ind.	Sept.	1909	....	

CLASS A—Continued.

Acetylene Report No.	Name of Machine	Manufactured by	Manufactured at	Date of Original Exam.	Date of Last Re-exam.
454	Phelps Measured Feed	...	Elkhart, Ind.	July 1907	March 1909
404	Pilot, Model B.	Co.	Chicago, Ill.	Oct. 1904	Jan 1909
386	Pilot, Model C.	Co.	Chicago, Ill.	Feb. 1903	Jan 1909
428	Pilot Model D	Co.	Chicago, Ill.	May 1905	Jan 1909
381	Radiant		Canandaigua, N. Y.	Feb. 1903	Dec. 1908
388	Reliance		Dayton, Ohio	Dec. 1904	March 1909
482	Stiles	Ill. for F. Ill., for	Elkhart, Ind.	Sept. 1909	......
482	Strimple	Strimple's Acetylene Co., Peoria, Ill.	Elkhart, Ind.	Sept. 1909	......
354	Sunlight Omega	Sunlight Gas Machine Co.	New York, N. Y.	July 1902	Sept. 1909
347	Victoria, Model B	Victoria Mfg. Co.	Auburn, Me.	Feb. 1902	Sept. 1909
385	Western	Western Gas Company, Chicago, Ill.	Reddick, Ill.	Sept. 1908	......
430	Accelerator	General Light Co.	Philadelphia, Pa.	Sept. 1906	Feb. 1909

This generator is considered suitable for use only when installed in a masonry pit, with the generating water below the frostline, located outside of and at least 30 feet removed from buildings.

CLASS B.

STATIONARY APPARATUS FOR CENTRAL STATION SERVICE.

Acetylene Report No.	Name of Machine	Manufactured by	Manufactured at	Date of Original Exam.	Date of Last Re-exam.
239	Williamson	Acetylene Apparatus Mfg. Co.	Chicago, Ill.	April 1902	Jan. 1909

CLASS D.

PORTABLE TABLE LAMPS.

Acetylene Report No.	Name of Lamp.	Manufactured by	Manufactured at	Date of Original Exam.	Date of Last Re-exam.
429	Beck Iden	Acetylene Lamp Co.	New York, N. Y.	Sept. 1905	June 1908

CAUTIONS.

1.—Calcium carbide should be kept in water-tight metal cans, by itself, outside of any insured building under lock and key, and where it is not exposed to the weather.

2.—A regular time should be set for attending to and charging the apparatus during daylight hours only.

3.—In charging the generator chambers of water-feed machines, clean all residuum carefully from the containers and remove it at once from the building. Separate from the mass any unslaked carbide remaining, and return it to the container, adding new carbide as required. Be careful never to fill the container over the specified mark, as it is important to allow for the swelling of the carbide when it comes in contact with water. The proper action and economy of the machine are dependent on the arrangement and amount of carbide placed in the generator. Carefully guard against the escape of gas.

4.—Whenever recharging with carbide always replenish the water supply.

5.—Never deposit residuum or exhausted material from water-feed machines in sewer pipes or near inflammable material.

6.—Water tanks and water seals must always be kept filled with clean water.

7.—Never install more than the equivalent of the number of half-foot burners for which the machine is rated.

8.—**Never test the generator or piping for leaks with a flame, and never apply flame to an outlet from which the burner has been removed.**

9.—**Never use a lighted match, lamp, candle, lantern or any open light near the machine.**

10.—See that the entire installation is in accordance with the rules of the National Board of Fire Underwriters, a copy of which will be furnished by your insurance agent, and obtain from your contractor a written guarantee that these rules are complied with.

Note.—Failure to observe the above cautions is as liable to endanger life as property.

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1st, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and two research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

University of Missouri

Engineering Experiment Station

Bulletin No. 2 June, 1910

WATER SUPPLY FOR COUNTRY HOMES.

By Karl A. McVey.

An improvement is noticeable at the present time in the sanitary surroundings of farmers' homes. This improvement is the natural outgrowth of the increased requirements for comfort and refinement in the home. The healthful pleasure of life in the country, either at the country residences or on the farm, so often marred by the absence of comforts which in city life come as a matter of course, is being brought about by what is known as "modern conveniences." The introduction of these improvements depends largely on having or providing an abundant supply of pure water. It is a great step toward insuring the health of the household dependent upon the water, and increasing the wholesomeness and healthfulness of the milk, butter, cream, and other products used on, and sold from, the farm.

The idea is general that water supply and house sanitation are extremely expensive. This, however, is far from being the case, and in the installation of a water system, if it be kept within the bounds of utility, avoiding that which is luxurious, the cost is considerably less than might be anticipated.

It is the purpose of this bulletin to outline some methods of water supply, draw attention to the importance of the sanitary aspect of the supply and to give an idea of the cost of making such improvements.

The methods of supply described are not new but have all been tried for some time, nor are any claims to originality made. It is believed, however, that the different methods are not generally known and an exposition would be of value. The costs, which have been given, of course can only be taken as approximations, but at this time and place are reasonably close to those which would prevail in the rural districts of the state. The question of water supply naturally leads to a consideration of sanitation and sewage disposal, which phase of the question will be taken up in a following bulletin.

SPRINGS.

Springs are the natural outlets at which underground water flows out at the surface. In some parts of the country springs yielding pure water are numerous and are a cheap and valuable source of supply. As a rule their waters are palatable, wholesome, and free from organic impurities owing to the natural filtration going on while it passes through the subterranean strata before it reaches the surface. It is best and most convenient if springs are found located at an elevation considerably higher than the house and grounds to be supplied, for then the water may flow by gravity and the necessity of some form of pumping machinery is done away with.

In contemplating a water supply obtained by tapping a spring, it is of importance to give attention to the variation in the yield of the spring, which occurs almost regularly at the different seasons of the year. It is much safer in all cases to defer the gauging of the spring until after dry weather has set in, and to select a spring only in case it yields, even at such times of drought, an excess of water over the maximum supply required.

To protect the spring against contamination it is necessary to wall it in, or still better, to construct a small storage basin in which the night flow can be stored, thus providing a reserve. This should have a reasonably tight cover to exclude surface impurities, dust, and animals. A cheap method of obtaining this storage would be to direct the flow from spring into a sunken barrel and from this have the supply pipe leading to the house. This pipe should enter the side of reservoir about six inches from the bottom, thus permitting a settling of suspended matter to the bottom from which it can be periodically removed. A strainer should be placed on the outlet pipe, inside the barrel or other reservoir provided, to prevent any foreign matter entering, which the covering has failed to exclude.

In the popular mind springs are supposed to represent the purest of supplies, but under certain circumstances this type of ground-water may not be wholly pure. Often in rough and rocky districts the depth and thoroughness of percolation over and through rock masses is so limited that the water may not equal in purity the normal ground-water. Generally, spring waters before exposure to surface of soil are deficient in micro-organisms, as they represent filtered waters, but as they appear at the surface, the water comes again in contact with organic matter and soil bacteria, and they receive a considerable number of organisms from this course.

Thus can be readily seen the importance of walling in a spring where it issues from the ground and making the surface drainage good in the vicinity of the spring, forestalling the possibility of contamination by surface waters from cultivated, manured fields.

WELLS.

Wells are used in the country probably more than any other source of supply. Water from them is really rain water which has percolated through the soil down to a water bearing stratum; it is in some cases purified by its percolation through the soil, in others it is changed in character and made "hard" by reason of having dissolved and taken up mineral constituents from the geological strata through which it flows. While springs are natural outlets, wells may be considered artificial ones, for they have to be sunk, dug, driven, or drilled to the water bearing stratum, and furthermore, the water must be lifted by pumping to be of use, except in the case of true artesian wells which occur rarely in this state.

It is usual to distinguish between shallow and deep wells, yet there is no sharp demarcation between the two; the designations "shallow" and "deep" really refer more to the nature of the underground strata which the well pierces. Wells to a depth of from 15 to 30 feet, to water flowing in a superficial layer of gravel or sand which rests upon an impervious stratum are considered shallow wells. These wells should be looked upon with suspicion because they are liable to become polluted, particularly in densely settled regions, but not to a lesser degree on the farm, if they be located close to outhouses, cesspools, stables, or in close proximity to cultivated, manured fields.

These wells are either dug and lined with brick or stone, or "driven," that is, a pipe bearing a pointed perforated shoe is driven into the ground to a depth of the underground supply. These driven pipes are often only wrought iron tubes from one to three inches in diameter, and it may be mentioned here that the diameter of wells has not so great an influence on the yield as is commonly supposed. Very large supplies may be obtained from wells only 4, 6, or 8 inches in diameter.

In most cases the driven is superior to the dug well, because there is not the same amount of danger of pollution by surface leakage.

Deep wells sunk in gravelly or sandy soil, are driven or bored with tools similar to an auger or else a casing is forced through the earth into which the well pipe is inserted after the proper depth has been reached. In other cases, prevailing in most instances, when wells are sunk through rocky strata, chisel drills are used which are alternately raised and lowered, at the same time being rotated. Wells of this type are often wrongly designated artesian wells, as this term can with propriety be applied only to those wells in which water flows out at the surface.

Contamination of Wells: In locating a shallow dug or driven well, it is of importance that the sanitary aspect of surroundings be taken into consideration. It is generally believed that wells located above,

that is, on a higher level than privy vaults and cesspools, are free from pollution by these sources. This, however, is not always true for "above" and "below" refer, not to the surface slope, but to the direction the water flows underground, and to the relative level of the porous or water bearing strata. When a large quantity of water is pumped from a well the underground conditions of flow may be altered. The water in the well would not alone be lowered, but also the surface of the underground water sheet for a distance all around the well. This distance increases with the amount of pumping, and while cesspools might under ordinary conditions be without the zone of contamination, pumping much water from the well will bring them into this zone. The fact whether a connection between well and cesspool exists may be established by several tests; one of the simplest being the salt-test, in which a large quantity of salt is thrown into the cesspool, then testing the water in the well by a chlorine test. Another is in the use of fluorescent "uranine," which gives to the well water a bright aniline green color.

The importance of protecting the farm well from surface pollution can not be over estimated. To bear out this statement we cite the results of the work of the Geological Survey of the United States Government in examining the farm water supplies in the State of Minnesota. Of 79 supplies examined, 20 were good and 59 polluted. In an examination of 28 dug wells, 15 had poor surface drainage and for other reasons 20 out of the 28 have a poor sanitary aspect. The drilled and cased wells show up much more favorably. It is safe to assume that the same results would be shown by an examination in the rural districts of Missouri. The remedy in most cases is easy; and lies in providing a tight impervious covering to shed all surface water and by giving the upper end of the well a water-tight lining to a depth of several feet. This can be done to the old well, or the new one under construction, by having the upper courses laid in a good cement mortar, and the surface, preferably the outside, covered with a coating of cement about three-fourths inch thick to a depth of 4 or 5 feet. The surface of ground surrounding the well should be given a gradual slope in all directions from the well curb.

The purification of a water supply is not of much interest to the dweller of a country house, for in most cases a pure supply is readily obtainable. However, there is one item under this subject well worth considering and that is, the growth of algæ which is likely to occur in pure waters. Algæ is a species of subaqueous fungus growth which usually appears as a green scum. While this is not considered detrimental to health, it gives to the water a peculiar, fishy flavor which makes it unpleasant for drinking. There is a cheap and very efficient remedy for the treatment of this condition, which con-

sists in making a dilute solution of copper-sulphate (blue-vitriol) in the water affected. The usual method of doing this is to immerse in the affected spring, pond or tank, a coarse bag containing an amount of copper-sulphate sufficient to make a strength of about one in four millions—something like one and one-half grains in weight of the sulphate to each 100 gallons of water. The growth of this fungus may be so prolific as to stop up the pipes from the tank or springs.

CISTERNS.

In localities where underground water is hard to obtain and unfit for use, cisterns are a very common form for farm water supplies. They are used for the storage of water from various sources but usually for rain water. They may be constructed of brick and mortar, concrete, stone under-ground, or of galvanized iron placed in any convenient place. If well located and protected the latter should be satisfactory. It is the common practice to place these iron tanks above ground and during the summer season the temperature is higher than that of the water in the underground types, and the growth of organisms, which are usually present in waters collected from roofs is encouraged rather than discouraged. A roof which catches the water for a cistern also collects anything carried in the air. The character of the materials deposited there will, of course, depend upon the locality and season of the year. Some of the most common are dust, dead insects, excreta of birds, and spores of plants. The water from new roofs is in nearly all cases unfit for use, and will have to be discarded for the first few rains.

The opportunities for pollution, after the water enters the cistern depend chiefly upon the construction and protection of the types of cistern in use. Leaks offer one of the greatest opportunities for pollution if the cistern be located beneath the surface, for sometimes ground water has free entrance. Ground water around cisterns is very frequently polluted, for in its passage through the surface soil, very little if any, purification is effected. It is better if cistern be so constructed that no surface water is allowed to filter into it. The quality of the cistern water can be much improved by installing a device for turning away the water caught during the first part of a shower. There are many automatic devices for accomplishing this, but few are in common use. A simple two-way valve at the bottom of the down spout to be turned by hand is a common and efficient contrivance if properly used.

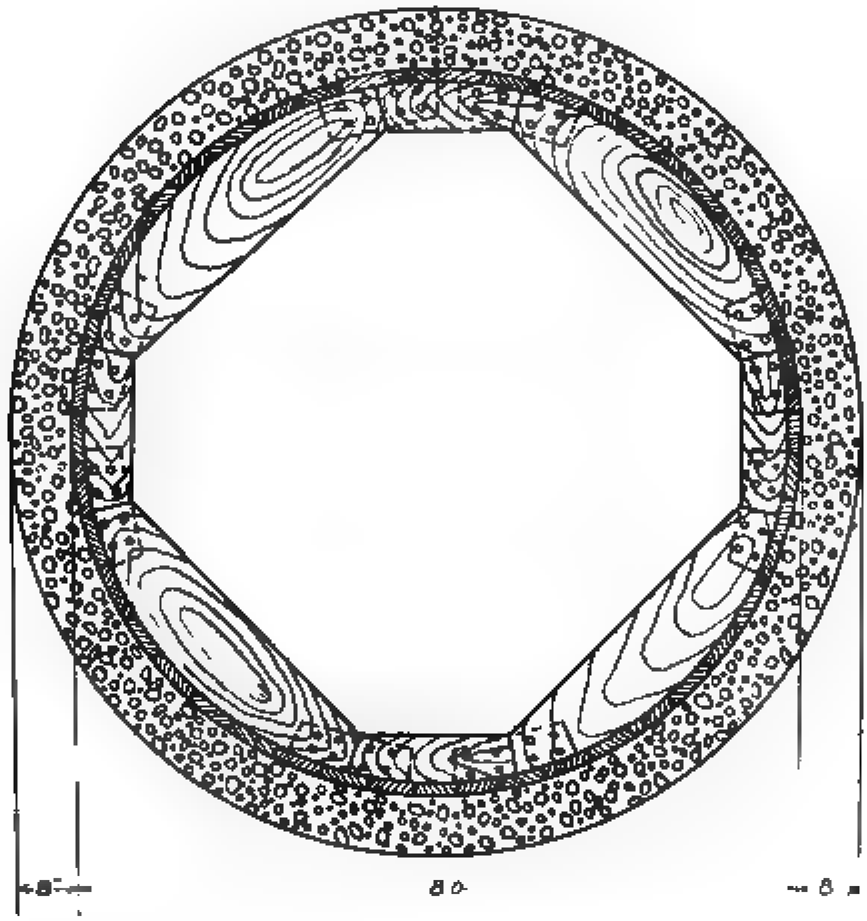
While the absence of lime salts renders it desirable for cooking, and its softeness recommends its use in the laundry, rain water on the whole is not to be considered as suitable as a pure ground water for domestic supply.

From a sanitary viewpoint, the safest and most durable underground cistern is probably that made of concrete. The designs for two of this type, together with the probable cost will be gone into.

Concrete Cistern: Make a circular excavation 16 inches wider than the desired diameter of the cistern and say 14 feet deep. Make a cylindrical inner form the outside diameter of which will be the diameter of the cistern. This form for a 14 foot hole should be about 10 feet long. Saw this form into sections for convenience in handling. Lower these sections into the cistern and then unite them to form a near perfect circle, blocking them up 6 inches from the bottom. (See figure 1.)

Make a concrete of Portland cement one part, clean sand 2½ parts, and gravel or broken stone 5 parts—which is known as a 1:2½:5 mixture. Mix in small batches just soft enough to pour. Fill in space between form and earth with concrete, and ram or puddle with a narrow scantling to keep from forming rock pockets. To construct the conical portion, build a floor across the top of the cylindrical form, leaving a hole in the center two feet square. Brace this floor well with uprights from the bottom of the cistern. Around the edges of the hole, and resting on the floor described, construct a vertical form extending a little above the surrounding ground. Build a cone shaped mold of earth or sand wetted good from the outer edge of flooring to the top of form around square hole and smooth well with a trowel or float. Place a layer of concrete 4 or 5 inches thick over the cone of sand and smooth to outer edge of side wall. After setting for a week one of the floor boards can be removed and the cone form of sand will fall gradually to bottom of cistern from where it can be easily removed together with the rest of the lumber used for forms. The bottom should be laid of same material as walls about six inches thick. If the water comes to the cistern from the house roof, and a kitchen pump is used, these pipes should be placed through the forms before concrete is put in so that they may be rigidly held in place. The materials for two different sized cisterns and their approximate cost is shown in table 1.

Fig. 1.



CONCRETE CISTERN SHOWING ARRANGEMENT OF FORMS.

TABLE 1.

Cisterns—MATERIAL AND COST.

14' deep (10' cyl. 4' cone) 8' diameter, Capacity 3 800 gals.

	Parts.	*Amount.*	*Cost.*
Cement	1	43 bags	$17.20
Sand	2½	4½ cu. yds.	6.75
Gravel	5	9 cu. yds.	27.00

Lumber for forms, 225 bd. feet.

13½' deep (10' cyl. 3½' cone) 6' diam. Capacity 2 100 gals.

	Parts.	*Amount.*	*Cost.*
Cement	1	31 bags	$12.40
Sand	2½	3 cu. yds.	4.50
Gravel	5	6½ cu. yds.	19.50

Lumber for forms, 200 bd. feet.

The cost of a cistern can be made close to the cost of materials provided the sand and gravel, and the lumber for forms are easily obtained. The labor item will probably equal that of any type of cistern but scraps of lumber can be used in the forms, or new can be bought and when through with can be used for other purposes. If there is a neighboring creek, sand and gravel can be had from it, but care must be exercised in collecting or it must be washed clean before making into concrete. Thus it will be possible that only the cement will have to be purchased on the market.

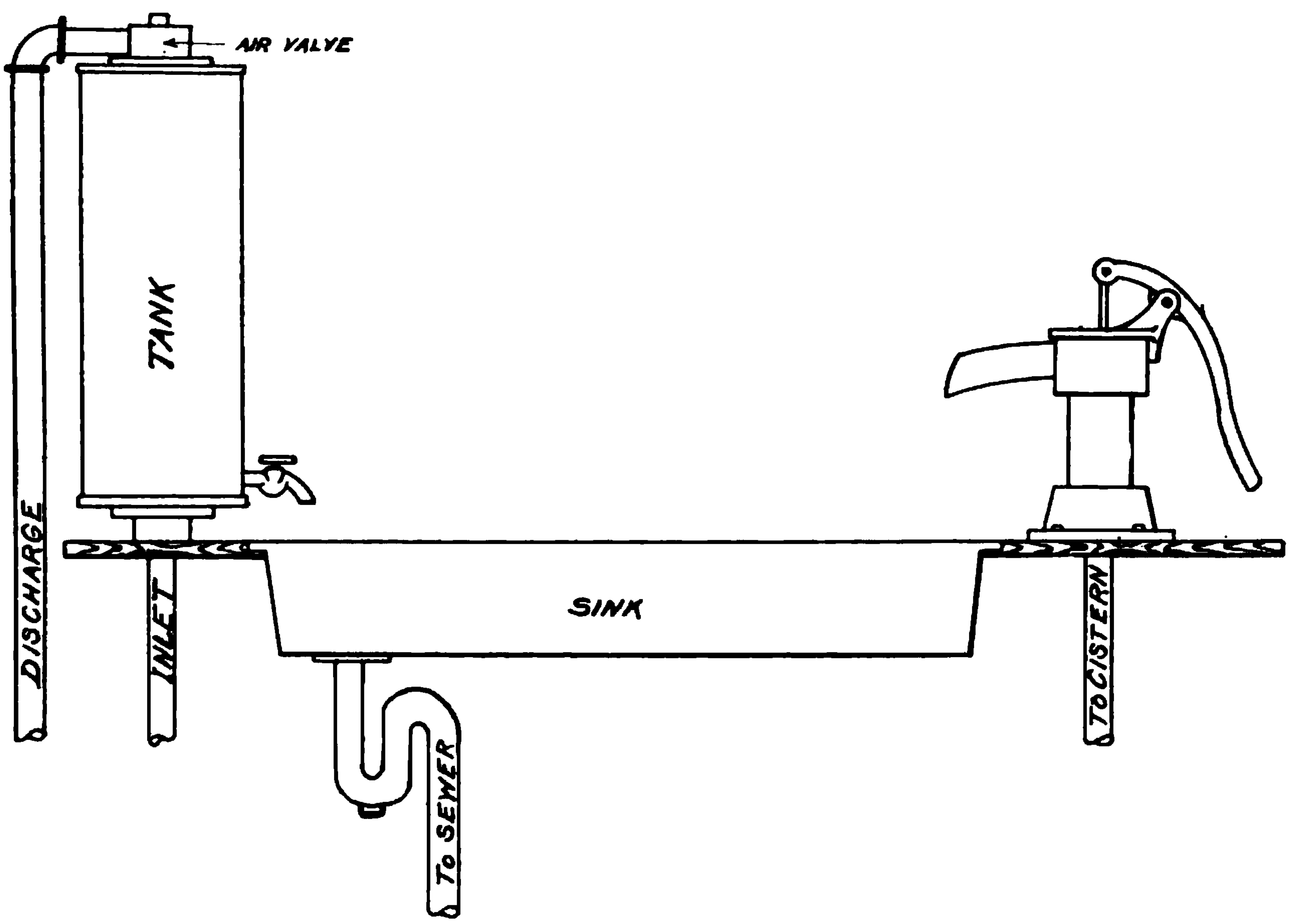
A farmer in central Missouri built a concrete cistern 16 feet deep by 10 feet in diameter at a cost of $70, exclusive of the labor of his helper. As his system is ingenious and can be duplicated on many farms throughout the state, we will outline it here.

Advantage is taken of a hill which rises higher than any of the barn yards. On this was erected the concrete cistern, half above the ground and half below. This is filled by a 6 foot windmill erected over a nearby dugout spring, which runs almost continuously. From this cistern pipes are laid and water flows by gravity to three concrete watering troughs situated at convenient points in the barn yard. The water level in each trough is controlled by an automatic float valve. As the cistern is large, storage enough is provided to tide them over the days during which there is insufficient wind to work the mill.

Use of Kitchen Pump: A small force, or pitcher spout pump placed at one end of the kitchen sink, with the suction pipe reaching to the cistern, is a convenient means of getting the soft water supply if the more expensive method of using a gravity tank or a pneumatic tank and piping the soft water to wash basins and bath tub are not

desired. Figure 2 shows in outline such an arrangement supplemented by what is known as an automatic house tank. This tank is placed at end of kitchen sink and water from windmill pump runs through it and then to stock tanks or barns. An air-valve at top of tank lets out any trapped air and tank fills with water. This allows the freshest and coolest water in house for drinking. The capacity of the tank should be 25 or 30 gallons to provide a reserve if the mill should stop pumping. A relief valve is placed in line pipe in well and is so arranged as to open at a certain pressure. It has no connection with working of the tank except in cases of extreme pressure, when it opens to relieve tank and insures against bursting

Fig. 2.



should the pipes become clogged or frozen. An estimate of the cost of such an installation as shown in figure 2 is a follows:

Cistern pump, 3 inch cylinder	$ 8.00
Kitchen sink, 18 x 30 inches	6.00
Tank complete, with air and relief valve	11.00
Pipe, say 25 ft. 1¼ inch galv.	5.50
Pipe, say 30 ft. 1 inch galv.	4.80
Installing above	4.00
Total	$ 39.30

The last three items, of course, can only be roughly estimated, as the locations of cistern and well will determine the length of pipes needed.

ELEVATED TANKS.

House Tanks: The water required at the farm buildings may be stored in inside tanks, which may be located in the attic or in the barn. These tanks are of wood, lined with copper, or of wrought iron or steel. The wood tanks while usually constructed square or oblong for use in the attic of the house, can be made in most any shape and be adapted to utilize any available space under the roof of the house. The objection to inside tanks is that their size must necessarily be limited, not only to the want of space but also because of the heavy weight of water which can not always be safely carried. This is more readily appreciated when reduced to figures. Say a tank holding 200 gallons is placed in the attic; this means a weight of 1666 pounds, exclusive of the tank which weighs about 125 pounds; which means that provision has to be made in the construction of the house to sustain this safely and this in the majority of cases can not be done without considerable expense. This objection is not so much the issue if the tank be placed in the barn where the necessary supports can be conveniently erected.

Another objection to placing the tank indoors is the socalled "sweating" which occurs when the tank is filled with cold water. It is especially bad in the case of bare iron tanks. This phenomenon is due to the condensation of the moisture in the air, on the outside of the tank. When the difference in temperature between water in the tank and the surrounding air is great, this condensation may be collected in such quantities as to run down the sides of the tank, endangering the plastering of the rooms below. This may be of little consequence in barns. This difficulty is overcome by using metal-lined wood tanks, or providing a covering of some kind—the frost-proofing would serve this purpose.

Outdoor Tanks. For the majority of farm buildings water can be raised into, and stored in outdoor elevated tanks. These may be made of wood or sheet steel and the supporting structure be of wood, steel, or masonry. Combinations often occur such as a wooden tank on steel tower, or an iron tank on a wooden tower. If left open and bare, elevated tanks often mar the landscape, so in nearly all cases they are covered and ornamented in some way. Since protection has to be afforded from frost, this wood covering can be nicely finished and painted, when it will add, rather than detract anything from the scenic value. Tank towers should be proportioned and constructed so as to be amply strong to carry their heavy load. They must be on firm foundations carried below the frost line to resist the heavy wind pressures to which they are subjected. The height of tower is determined by the pressure under which the water is to be delivered.

Wooden tanks of any appreciable size are always built round, because the circular shape is the best to secure tightness. Cypress lumber is used largely in the southwestern states, while in the East white pine is preferred. The strength of wooden tanks depends chiefly on the hoops which are either flat or round. The round hoops are the best because they can be easily examined, and protected from rust by frequent painting. It is essential in the erecting of a wood tank to support all its weight on the bottom. This is done by laying sleepers short distances apart across the entire base, and sawing them off a few inches inside the tank circumference.

The reasons why wooden tanks are preferred to steel tanks is that the latter are more difficult to erect, they give trouble by sweating, and have to be painted frequently to keep from rusting. It is also harder to protect a steel tank from freezing. Where large capacities are necessary, of course steel tanks are used, but for country estates the wooden ones are preferred. In practice it is found they will last from 15 to 20 years, and they can be bought and put up for much less money than can the steel tanks.

PNEUMATIC SYSTEM.

In addition to the attic and tower tanks which are now so generally used to supply country houses, there is another system, known as the pneumatic water supply, which has many advantages over the older methods. This system is of comparative recent origin and depends in its operation upon compressed air. The use of this system is dependent only on one condition, and that is, the ability to secure a good supply of water from well, cistern, or spring, from which it can be pumped. The most important advantage of this system is the fact that the tank may be located anywhere; either in the cellar, stable, underground, or at any other place where there is no danger of freezing.

This allows the water in the piping to be maintained under pressure without using an elevated tank with its attendant evils, such as danger of leakage, straining of timbers under its great weight, etc. The tank is of wrought iron or steel, air-tight, and can be filled by windmill, power pump driven by gasoline engine, or by hand. Either a horizontal or vertical tank may be used, as suits the convenience.

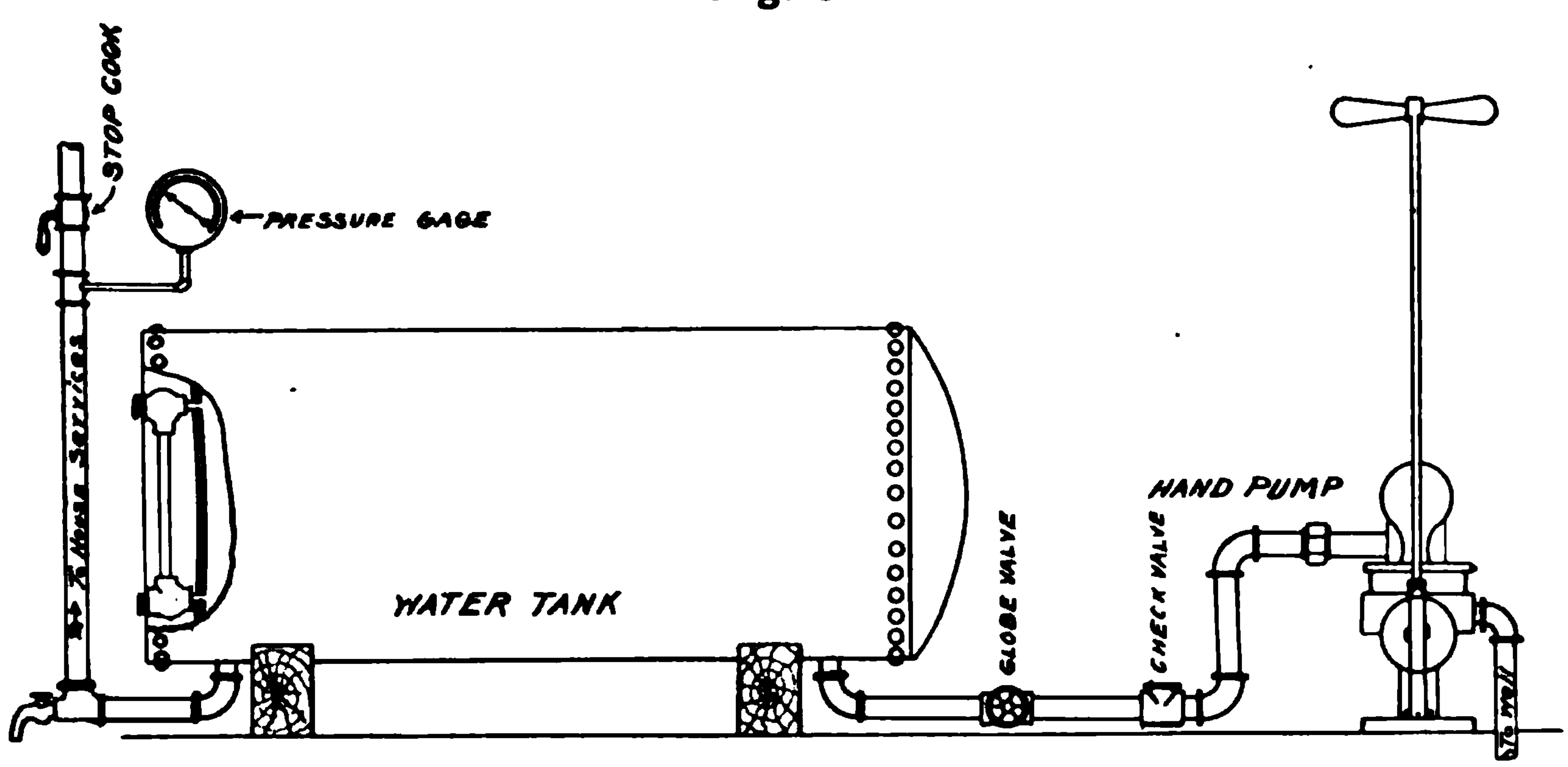
Principle of Action. Water is pumped into the bottom of this air-tight tank, and as the water rises the air above it is compressed. The expansion of this compressed air will force the water through the supply pipes at the bottom of the tank to points where the water is required. The pressure in tank is increased by pumping water into it and decreased by drawing it off. The correct amount of air can be supplied and maintained by an automatic air valve, by a pump that forces both air and water into tank at the same time, or by a hand

air valve. This is necessary to prevent tank being completely filled with water, a condition called "water-logged," which will prevent any pressure being gotten up.

If the tank is supplied by a windmill, an automatic pump should be used which will throw the wheel out of gear when a certain pressure is reached, and when water is drawn, the reduction of pressure will throw it in gear again. An installation of this kind has been in use on a Cooper county farm for the past four years. The windmill, an 8 foot mill on a 25 foot galvanized steel tower, and automatic pump erected cost $100. The pneumatic tank, capacity 6 barrels, was put in by a local firm for $60. The owner advises that the operation has been excellent, requiring practically no attention and since tank is underground, has experienced no inconvenience during freezing weather.

In Figure 3 is shown a complete outfit for the average sized country home. The tank is 30 inches in diameter by 8 feet in length, having a total capacity of 295 gallons and will deliver about 200 gallons without refilling.

Fig. 3.



As the space taken is small, it can be located in the basement. The water is pumped with a small hydro-pneumatic hand pump which is satisfactory provided the lift is not over 20 feet. On this pump a hand air valve is provided, so that by opening this and pumping the correct amounts of air and water can be maintained.

The approximate cost of an outfit of this kind ready to connect to service pipes in house is about $64, being proportioned as follows:

Pneumatic tank, 30 in. x 8 ft., cap. 295 gal.	$ 42.00
Hand pump, 3 in. cyl. 1¼ in. suction	10.00
Gage and water glass fittings on tank	5.00
Pipe fittings (shown in figure)	7.00
Total	$ 64.00

The advantages of a pneumatic system are many. It not only does away with the attic tank but allows the apparatus to be located conveniently to the pump, where the operation can be watched; the danger of freezing, common to elevated tanks placed outdoors is avoided, also the expense of erecting towers to support such tanks. The advantage to be gained by placing the tank underground, is that water delivered by it has nearly a constant temperature through the year. The application of this system covers a wide range, for it may be used on the farm to supply not only the house, but also the stables, wash room, dairy, lawns, and gardens.

If demand is not too great, one large tank may be used, otherwise the pressure will have to be pumped up oftener. It is good practice to have pumping time come but twice a week by having a tank large enough to hold supply for three days.

HOT WATER SUPPLY.

A hot water supply may be furnished by an independent heater and boiler in the basement, by connection to a coil in the furnace, or as is usual in country houses which have neither basement nor furnace, by a boiler and water back attached to the range in kitchen.

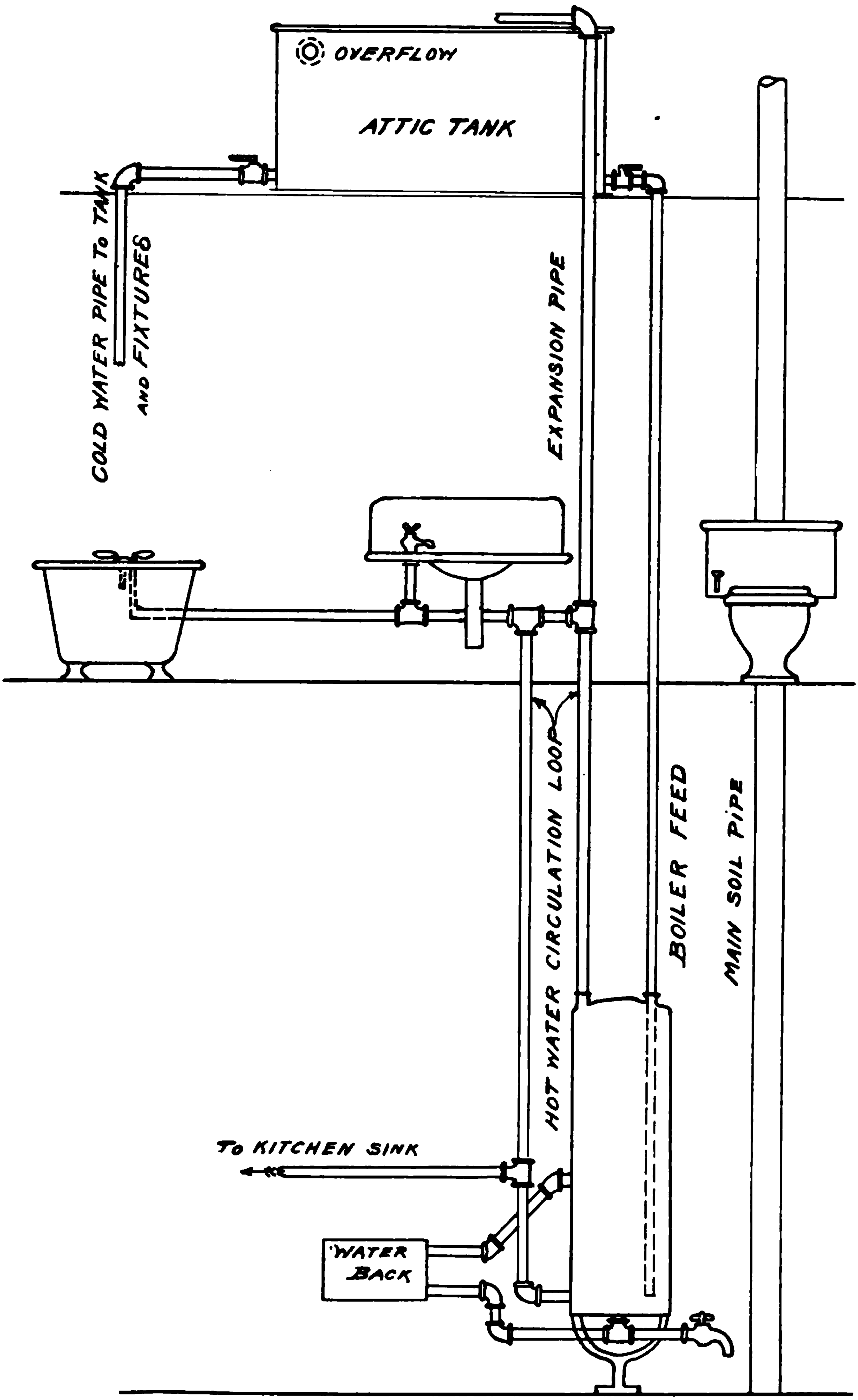
Whenever the house supply is from an attic tank, the hot water supply must be under tank pressure, in the use of which system an expansion pipe is necessary. In figure 4 is shown the arrangement of pipes for a successful water heating and circulating system.

The cold water should always enter the boiler at some distance below the entrance point for hot water from the range water back. The kitchen boiler is simply a storage tank to keep a supply on hand so that it can be drawn when needed. Certain hard waters will rust out a galvanized boiler in a few years while a copper boiler will last indefinitely, but its cost is prohibitive, and in nearly all cases these kitchen boilers are galvanized iron of 30 to 40 gallons capacity. As difference in price is small, it is preferable to install the larger tank.

The upper pipe connecting the water back and boiler should not sag but have a continuous rise from range to boiler, entering boiler as high as is practicable, and be of reasonably large size, in order that circulation will be good and water in boiler will heat rapidly. To prevent pounding and the consequent noise in the boiler, the expansion pipe is provided to allow steam and air a ready escape. Any sediment accumulating in boiler can be drawn off at the faucet at base of boiler, which in all cases should be provided.

Since when using an attic tank the available water is limited, it is desirable to draw hot water from faucets at the instant of opening, without having to wait until a long pipe is emptied with the consequent waste of water. The use of circulating pipes, if properly

Fig. 4.



ARRANGEMENT OF HOT WATER PIPING.

installed obviates this disadvantage. As shown in the figure, the hot water pipe is started from the top of the boiler, where the hottest water is, carried up to highest fixture, then down to base of boiler. Since it is preferable to use the least pipe, bath room should be located directly above the kitchen, as it not only simplifies piping but secures a much safer plumbing installation.

For simplicity, only the hot water piping is shown in the figure. A reputable plumber furnishes the writer with the cost of this installation as follows:

Attic tank, capacity 150 gals.	$ 6.50
Kitchen boiler, capacity 40 gals.	10.00
Kitchen force pump	8.00
Boiler connection to range	3.50
Piping, approximate	35.00

He estimates the total cost of installing the water and sewer connections to fixtures as shown, at $130.

If the house has a basement, the heating arrangement can be supplemented by a small water heater in basement to be used when hot water is needed and it is not convenient to have a fire in the kitchen range.

AVAILABLE POWER.

In each case the situation will determine what will be the most economical and convenient means of forcing water into the storage tank. The source of supply, the amount required, the available fuel and labor cost will all have a bearing on the matter. The hydraulic ram and the windmill have the advantage of operating without fuel, but fall must be available to use the ram, while with the windmill the daily supply is not always under control. Gasoline and kerosene engines require fuel and attention, but the supply is easily regulated to suit varying demands.

Windmills: A good and simple way of securing a supply of water is by the use of a windmill. Where the machine is properly constructed it will pump large quantities of water without cost practically, for the wind is free and the cost of repairs is very small. To be most efficient and to take advantage of the wind from any direction the tower should lift the wheel about ten feet above the tallest obstruction. The galvanized steel towers have proved durable and are fast taking the place of wood towers.

A combination tower carrying both wheel and tank is being made by many of the manufacturing companies under the name of "suburban outfit." Like all outside tanks, these have to be guarded against frost and the pipes leading to them have to be protected. Pipes are protected by enclosing in two or more wood casings with

air spaces between. Combination pumping and power mills are also on the market at an additional cost, that will pump water, grind feed, shell corn, saw wood, etc.; but the heavier work must be done when there is a strong breeze. For pumping water in the central part of this state, where the average hourly wind velocity is about 9 miles per hour, 8-foot wheels on 35-foot towers are the most common in use. A division of the cost of one of these mills would be about as follows:

Thirty-five-foot galv. steel tower	$ 25.00
Eight-foot mill wheel	34.00
Pump, 2½" cyl., 3 way valve	14.00
Cost of erection	12.00
Total	$ 85.00

The following suggestions on windmill pumping may be of value. One of the most desirable features in this work is the efficiency of the mill in light winds. A pump used in connection with a windmill should be of smaller size than when operated by hand, for when hand pumping is resorted to, we want a pump which will elevate the maximum amount in the shortest time.

The requirements are different, however, in the use of windmills, for generally the windmill need not run but three or four hours a day to supply the tank with the necessary amount of water. During certain seasons of the year there are many days during which the wind is very light, in this locality in July and August. During these times the windmill should be under as light a load as possible in order that it may be certain to perform some work. Therefore a small pump, even though unable to furnish but half that which could be pumper by hand during the same period, will prove most satisfactory. This small pump will allow the windmill to work a great number of hours during light breezes, and will be found to pump more water during the twenty-four hours of a day than a larger pump would.

The character of the well and its depth should be known—whether it is a driven, drilled, or dug well; if drilled, the inside diameter of casing should be known; the height and distance through which water is required to be raised. This last dimension is taken from the water level in well to the base of the elevated tank. The amount of water entering well during dry seasons should be known, the capacity of tank to be used, and the height of tower necessary to raise wheel free from obstructions. All this information should be given the manufacturer when purchase is contemplated as they determine the cost of outfit, and allow an intelligent estimate to be made.

Gasoline Engines: Small gasoline, also kerosene, engines are now manufactured for the express purpose of doing pumping and other work about the farm. They have one distinctive advantage over other kinds of power, in that the water can be pumped in the quantities and at the time wanted, and the size of storage tank can be very accurately chosen. An engine can be selected which will burn natural gas, gasoline, kerosene, or alcohol. These engines do not require a great amount of skill to run them. They require little fuel and can be used for driving other light machinery when not needed for pumping water. Since there are many uses to which they can be put, it is well to select one of the many portable types now on the market, if gasoline or kerosene is to be the fuel used. They are mounted on skids or trucks and can be easily attached to churns, feed mills, corn shellers, grain fans, etc. For the sake of general utility, it is best to choose an engine of from 4- to 6-horse power. If only pumping is required or wanted, a 2- or 3-horse power engine will furnish ample power. With the advent of denatured alcohol, there is a possibility of a more economical fuel. A good 2- or 3-horse power engine can now be purchased at a cost of $80 to $100.

With any good, small, stationary gasoline engine working under favorable conditions, a fuel consumption as low as one pint of gasoline and 1.4 pints of alcohol per horse power hour may be reasonably expected, and the difference is slight with the well constructed engines now on the market. Any gasoline engine of the ordinary types can be run on alcohol fuel without any material change in the construction of the engine. The difficulties likely to be encountered are in starting and in supplying the correct amount of alcohol fuel, which is considerably larger than the quantity of gasoline required. The fuel consumption, which governs the cost of operation, depends chiefly upon the horse power at which the engine is being run and upon the setting of the fuel supply valve. It is easily possible to double the cost of fuel used, either by running the engine on a load below its full power or by a poor setting of the fuel supply valve.

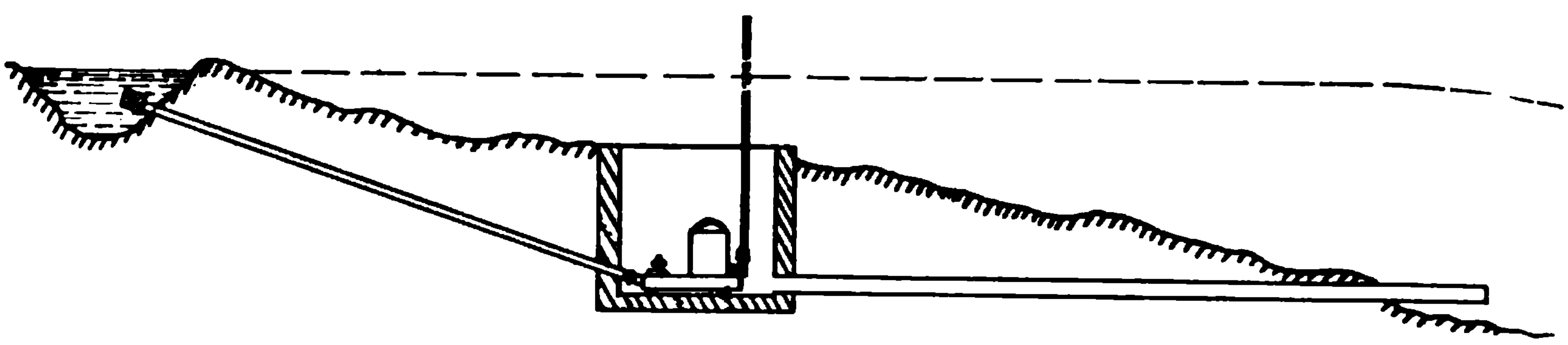
On a dairy farm in Boone county a gasoline engine of 4-horse power pumps water from a nearby creek to a cistern on a hill, from which water flows to the house and barns by gravity. The owner operates engine a few hours twice a week, and states that the average fuel cost is only 15 cents per week, and that three dollars a year will cover the cost of repairs to pumping plant.

Hydraulic Rams: Where some means of pumping has to be used to furnish the water supply, probably the most economical method lies in the installation of a hydraulic ram. It can be used to fill the storage tank if the source of supply is a spring, flowing well, or running stream from which enough fall to supply the power

can be obtained. In a proposed installation the first items to be considered are the supply and the available fall. Its use is practicable with a flow of only two gallons per minute and a fall of 18 inches. These are the lower limits and any increase in quantity and fall only betters conditions; increasing the amount pumped and the distance and height through which it can be elevated. The relation between the height of spring or supply, above the ram and the elevation to which the water is to be delivered, determines the proportion of water raised to that which runs to waste.

Water falling from higher to lower levels has energy in amount depending upon the distance it falls and the quantity falling. In the hydraulic ram this energy is made to pump and elevate water, thus utilizing to advantage that which otherwise runs continuously to waste. The power which operates the ram is created by the velocity of the water supplied to it, hence it necessary to have a fall or head of water the same as if a small water wheel was to be operated.

Fig. 5.



LOCATION OF HYDRAULIC RAM.

In operation, the ram is a combined pump and water motor, working in pulsations by a kind of water hammer caused by the abrupt stopping of the flow in the drive pipe. The energy the water has acquired is spent in forcing part of the water which drives it up into the tank or other reservoir through the delivery pipe.

The best locations for a ram are at the hillside spring, where the natural fall of the land furnishes a working head, or near a natural fall in a stream; leading supply from stream above falls to ram, and then letting it run back into stream below the falls. If spring is the source, the fall can be increased by walling in with brick or concrete, provided this does not materially decrease the flow. In the figure the natural fall is increased by placing ram in pit and letting waste water out through ordinary drain tile.

For the average farm house using say, 150 gallons per day, a ram which will operate on four gallons per minute will furnish the supply, and that too—through a thousand feet of pipe. It may be safely calculated that conveying water from 50 to 60 rods, one-tenth to one-fourteenth of the supplied water can be raised and

discharged at an elevation ten times the fall. A rule given by one of the most prominent ram manufacturers reads thus: "To find the quantity of water which a ram will deliver, multiply the fall in feet from the spring to the ram, by the number of gallons per minute supplied to it; divide this product by twice the height to which the water is to be forced, and the result will be the quantity of water (in gallons) per minute delivered by the ram at point of discharge.

Appended is a table showing the sizes of rams now on the market and the approximate cost of same.

HYDRAULIC RAM SIZES.

Gal. per min. to operate.	Size of drive pipe in inches.	Size of discharge pipes in inches.	Price.
1½ to 4	1	½	$ 8.00
6 to 14	2	1	18.00
10 to 25	2½	1¼	25.00
20 to 60	4	2	45.00
30 to 120	6	2½	75.00

POSSIBILITY OF INTRODUCING PLUMBING INTO HOUSES ALREADY BUILT.

It goes without saying that plumbing can be put into a house more conveniently at the time the house is being built; but if this has not been done there is nothing to prevent its being installed afterward. Installing the plumbing may conflict with the household routine for a few days, but as all pipes should be run exposed for sanitary reasons, aside from cutting through ceilings and floors, little inconvenience is met with in putting the fixtures and pipes in place. A water back can be placed in almost any kitchen range and attached to a hot water boiler.

As an illustration of the cost of introducing such conveniences, some actual cases are cited. In an eight-room two-story house having in bathroom a lavatory, bathtub, and watercloset, one lavatory in bedroom; in kitchen a sink and 30-gallon range boiler; and in laundry one cold water faucet, these fixtures were set up with complete supply and waste pipe connections for $180.

In another six-room cottage employing an attic tank, water is supplied to bathroom fixtures, consisting of lavatory, bathtub, and watercloset, the kitchen sink and hot water heating tank, the total cost was $115.

Electric Pumping: There are many suburban residences on the outskirts of towns and villages to which the electric light mains have been extended, or could be very easily. If this condition prevails and advantage is taken of same for lighting the house; electricity

can be made the power to do the water pumping. If an electric motor be used, the arrangement should be such that it will be automatic in its action. Whether the system be elevated-tank or pneumatic, it should be so arranged that the level of water in the elevated tank would not rise or fall below certain heights, nor the pressure in the pneumatic system vary more than a few pounds.

These pumps are rather attractive in appearance so would not be unsightly or take up much space if it were necessary to place it in the basement. Pump and motor are made in compact units either for belt or gear drive and operate practically noiseless. The size of the motor of course will depend upon the capacity of the pump; and the type, on the available current. Purchase of the whole unit had best be made from one firm, as motor and pump must be adapted to each other, and information as to the type of motor required gotten from the company furnishing electricity or from a local electrician.

A one-half horse power motor direct connected to a 2-inch by 4-inch cylinder pump has a capacity for ordinary lifts near 300 gallons per hour.

The first cost is comparatively large but the power cost and maintenance charges will probably be smaller than for any other except when hand power is used.

Conclusion: There are many modifications of the systems outlined, where soft and hard water piping is used, which are more or less complicated. In one of these hard water is supplied from a deep well and is used for laundry, kitchen and sanitary purposes, in the house, for watering stock and other outside purposes. The pneumatic tank is connected with a windmill or other pumping device, and is supplemented by a soft water tank in the basement. Water from the hard water tank is used to operate a water-lift which pumps from a cistern into the soft water tank in basement. This water lift is so constructed that when the pressure in the soft water tank equals the pressure in the hard water tank the lift will stop working and will not again start until water has been drawn off and the pressure reduced. Any system of this kind can best be worked out by a good plumber.

The requirements of no two families or homes are ever alike, but these suggestions are made with the hope that they may be a help in solving the question of water supply. The importance of sanitation and purity of supply have been emphasized, but none too strongly. The labor saved by having the water carried to the house, barn and garden will soon pay for the installation of some good system, while the value of the healthfulness secured by a supply of pure water and sanitary plumbing cannot be estimated in dollars and cents.

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and two research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

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University of Missouri

Engineering Experiment Station

Bulletin No. 3 September, 1910

SANITATION AND SEWAGE DISPOSAL FOR COUNTRY HOMES.

Introduction.—The demand for modernly equipped farm homes at a moderate cost is becoming an urgent one. Farmers throughout Missouri are striving to keep abreast of the times in modern methods of agriculture. Likewise they are seeking the latest and best practices in every line of activity pertaining to the industry of farming.

They are demanding that their homes be equipped with the same modern conveniences that the people of the city enjoy, and it is the call from them for information on modern farm sanitation that has led to the publication of this bulletin.

The greater part of the bulletin is devoted to the subject of modern sewage disposal plants for isolated houses. A portion has been given to the discussion of sewage disposal methods now employed on the farm, and still another portion to country plumbing.

It is the purpose of this bulletin to present several specific designs and to call attention to the necessity of home sanitation in a general way.

Sewage Defined.—Sewage is composed of the liquid and solid waste matter that flows through a sewer. The character of the foul matters thus carried off may be fecal, excretory, or of the nature of slop water.

The term as defined here may allude to the contents of the privy vault. dry earth closet, slop water basin, cesspool or the septic tank. Sewage may mean the contents of the cesspool, septic tank, etc., or it may refer to the waste material after its final deposit in a stream, ditch or upon a field. The term generally applied to sewage as it flows from the sewer to the final place of disposal is *effluent,* and should this word be found in subsequent pages of this bulletin it will be thus defined.

METHODS OF DISPOSAL.

The methods of sewage disposal may be conveniently divided into two general classes, namely: Water-Carriage Systems and Dry Sewage Systems. The latter will be taken up and discussed first, inasmuch as it is the one in more general use at the present time in rural communities.

DRY SEWAGE METHODS.

Under this head two subdivisions of the subject will be made. They are *privy vaults* and *earth closets*. Both of these methods, though crude, can be made healthful and sanitary if proper care is taken in regard to their arrangement, location, and operation.

The Privy Vault.—The privy vault is the method most commonly used at the country home. This system will continue to be used for a long time on account of its cheapness and economy. Some suggestions are offered by which its sanitary conditions may be improved.

The privy vault as ordinarily constructed consists of a small frame building erected over a pit which receives the refuse or fecal matter. For a time such a receptacle is satisfactory, but unless properly cared for it becomes a nuisance, obnoxious both to sight and smell, as well as a menace to health. This obnoxious condition of privies can be avoided by a generous use of lime and an occasional removal of the waste from the pit.

Water Supply Contamination.—Occasionally a privy vault will be found near a well, cistern, or other source of water supply. This may become polluted, due to the seepage of the sewage through the ground. Furthermore this sewage waste may be so clarified by passing through the porous earth that by the time it reaches the neighboring source of water supply it will be clear and apparently pure. Experience has taught us, however, that this water often contains disease germs which we have no means of detecting until we have been poisoned by them and have perhaps developed a case of serious illness.

Privy Vault Dangers.—Two of the common causes of the spread of typhoid fever are the contamination of the water supply, and the transmission of the disease by the ordinary house-fly. Instance after instance could be given where cases and even epidemics of typhoid fever have been caused by the pollution of wells or cisterns from neighboring privies which in some cases were located several hundred feet distant. The water in the wells was apparently pure and sparkling, yet it contained the germs of disease. Frequently a well or spring is polluted from a nearby brook or gully leading from a neighboring farm where recently there may have been a typhoid patient. Instances are on record where typhoid bacteria were transmitted a mile or two by this method. Hence too much precaution cannot be taken in the protection of the home water supply.

The privy vault often becomes a fly breeding place, and should therefore be as far as possible from the house. That flies do transmit disease, notably typhoid fever, there is no longer any doubt, and the privy vault should, as far as possible, be inaccessible to them. This may be accomplished by the use of screens. Another effective and inex-

pensive remedy for keeping the flies away from the closet is by a generous use of dry air-slaked lime applied daily.

Some precautions should be observed in connection with the building of privy vaults. Generally they should not be within one hundred feet of any source of water supply. Do not leave the excreta accessible to flies. Do not neglect the frequent removal of the waste material from the vault. If possible select the location of the privy vault so that the liquid waste will drain away from the premises into a ditch or gully rather than to have it pass near the cistern.

Earth Closets.—In connection with dry sewage systems we have the earth closet which is perhaps little used in this country, although employed to quite an extent in England. The earth closet is simple and cleanly and in many respects an entirely satisfactory substitute for the privy. The excreta should be received in a box or pail made to fit closely beneath the seat. The seat may be like that of an ordinary water closet. Each time the closet is used a small amount of dry earth is added. The action of dry earth is to deodorize and render harmless the waste matter of the closet. The receptacle should be emptied frequently. The out-house or closet should be well lighted and ventilated, and preferably plastered on the inside. With proper attention, this closet need not be built far from the dwelling house.

The earth used in such a closet should be dry, and if possible, porous and of a loamy nature. A very sandy soil is useless. Ashes are entirely satisfactory for this purpose. Authorities on the subject of sanitation recommend the "Dry Closet" rather than the "Privy Vault," because it is far more sanitary and becomes less of a nuisance.

Regarding earth closets, Gerhard states the following in the annual report of the State Board of Health of Maine:

"All that is needed is a common closet, a supply of dry earth, a water tight receptacle beneath, and a convenient way of disposing of its contents at quite frequent intervals. The receptacle should be wholly above the ground, and may consist of a metallic lined box, or half of a kerosene barrel with handles on it for removal, or better still, a galvanized iron pail. The receptacle may be removed through a door in the back of the closet or in front of the seat, or by having the seat hinged and made to open backward it may be removed in that way.

"The earth used should be common garden or field loam finely pulverized. Road dirt does well, but sand is not suitable. Coal ashes are also good. Whichever is used should be dry and screened through a sieve with about one-fourth inch meshes. The dry earth may be kept in a box set where it can be filled from the outside of the closet, or it is quite convenient to have one-half of the seat hinged, and beneath it a small compartment to hold the supply of earth. In this box there may be a small tin scoop which may be used for sprinkling over the refuse a

pint or more of earth each time the closet is used. The main thing is to use enough earth to completely absorb all liquids. This last requirement of course precludes the throwing of slops into the closet."

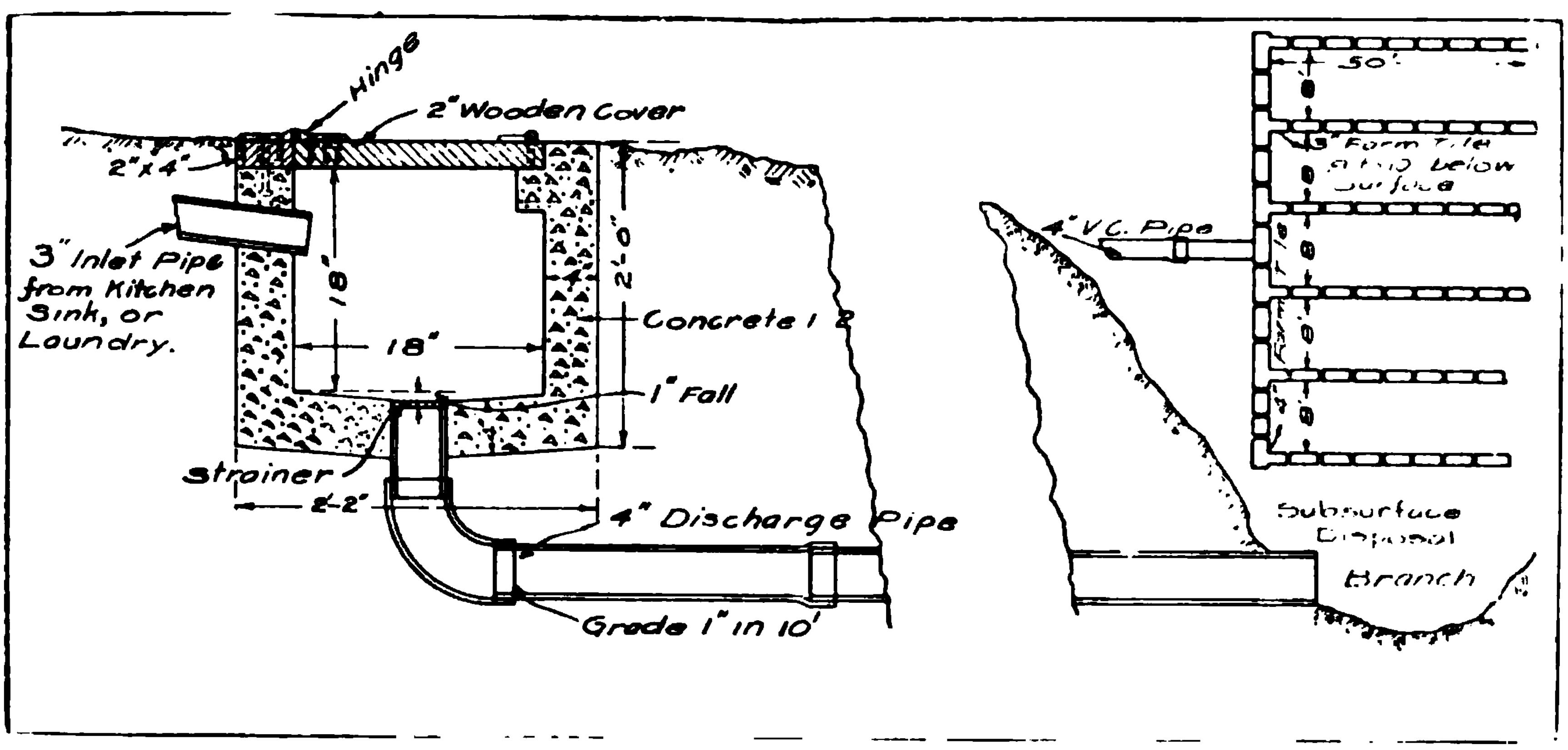
A CONCRETE SLOP WATER DISPOSAL BASIN.

The Tank.—Fig. 1 shows an arrangement for the disposal of slop water from the kitchen or laundry. In many farm houses where it is impracticable to install a complete sewage system, such a convenience as the concrete basin shown will greatly reduce the labor of disposing of house slops. It is entirely sanitary, and may be used satisfactorily either winter or summer.

The basin tank for receiving the slops is made of concrete. The mixture should be in the proportion of 1:2:4, that is, one part of cement, two parts of sand, and four parts of broken stone. The thickness of the walls should be four inches. The side walls should be vertical and the bottom should slope with a one-inch fall toward the center.

The size of the tank is 18″ wide x 18″ long x 18″ deep. A three-inch inlet pipe connects the tank to the kitchen sink or laundry. To aid

FIG. 1.



Slop Water Disposal Basin.

in the escape of offensive gases from the tank the wooden cover is perforated with several holes. This does not entirely prevent the escape of gases through the opening of the sink, but if the tank and pipes are flushed occasionally little difficulty will arise from the escape of gas through the sink into the house.

A four-inch discharge pipe connects the tank to a ditch located at a distance not less than from fifty to one hundred feet from the house.

In case the ditch cannot be given sufficient slope for readily discharging the waste matter as it comes from the concrete tank it will be better to use the subsurface or underground method of disposal which will be described later.

The wooden cover is hinged as shown to a 2″ x 4″ piece of wood which is bolted to the concrete in a manner as indicated in the drawing. The cover rests on a concrete projection at the side, and for convenience in opening, a ring is attached. A strainer should be provided in the bottom of the tank as shown in Fig. 1. This strainer is to prevent the entrance of solid matter into the discharge pipe which might thus become choked.

Construction.—Excavate to a depth of two feet below the ground surface. The finished size of the excavation is to be 2′-2″ wide x 2′-2″ long x 2′ deep. Locate the inlet and the outlet pipes according to the measurements indicated on the drawing, Fig. 1, giving each pipe sufficient fall to provide for a ready drainage of the slop. Use the earth as one side of the form, the other side of the form being constructed of one-inch lumber properly braced. First lay the side walls, and after about thirty-six hours remove the forms. Then lay the concrete in the bottom and carefully plaster the inside throughout. If crushed rock cannot be had, creek sand and gravel may be used with entirely satisfactory results. The concrete should be rammed into place.

Disposal of the Outflow.—The discharge from the above slop basin may be emptied directly into a running stream, or into a ditch some fifty to one hundred feet from the house. It will soon be purified and no offensive odors will form from it. The respective sizes of the inlet and discharge pipes should be three inches and four inches. They should be vitrified clay pipe with cemented joints. The slop tank should be fifteen to twenty feet from the house. The slope of the inlet pipe should be greater than the slope of the outlet pipe. A slope of one foot in fifty feet for the outlet pipe is desirable in order that it may be cleansed by the velocity of flow.

Subsurface Disposal of the Waste.—It is not possible in every case to dispose of the waste water as explained above. Should the ground be very flat, no ditch being available, other methods of disposal must be resorted to; chief among them being *subsurface* irrigation or disposal. In a subsurface disposal system a 3″ open-jointed drain title is used, laid with ¼ to ½ inch open joints, and to a slope of one inch in twenty-five feet. It is very essential that the tile be laid to a uniform slope. If possible the ditch should be excavated eight to twelve inches below the pipe and filled with sand, gravel, cinders, or other porous material, to aid in the immediate filtration of the waste water.

The tile should be laid from eight to twelve inches below the surface of the ground. It is essential that the drain tile be as near the surface of the ground as possible in order that the waste water may be purified by the oxygen which is present in the surface layers of the earth. At a greater depth this purifying process is greatly retarded due to the absence of oxygen. Should the ground be of a compact or clay nature,

a greater length of drain tile will be necessary, as also there will be greater need for the porous material beneath the tile.

The approximate cost of such a slop water disposal system is given below. If the waste water is emptied into a ditch or running stream the cost of slop basin will be $5.85 as shown below. If the subsurface disposal scheme is used, then an additional 50 feet of 3" pipe drain tile will be required. Fifty feet of drain tile at three cents per foot will add $1.50 to the cost, making a total cost of $7.35.

Approximate Cost—Labor not Included.

Cement, two sacks at 40c	$ .80
Hinges	.25
Ring	.10
Sixty-five feet of vitrified clay pipe at 6c.	3.90
Wooden cover	.25
4" elbow	.35
3" elbow	.30
Total	$5.85

CESSPOOLS.

The general definition of a cesspool is a tank into which the house sewage is discharged, said tank retaining the solid and sometimes the liquid matter until removed. There are two types of cesspools, viz., *leaching* and *tight* cesspools.

The leaching cesspool is built of loose brick or stone without the use of cement or mortar. Through the crevices in the side of the cesspool the liquids leach out into the surrounding soil leaving the solid matter to remain in the cesspool until removed by pumping or by similar means.

The tight cesspool is built of brick or concrete, it being essential that the cesspool be water tight. The liquid is removed by being drained out through a drain pipe. The solids are removed as in the leaching cesspool.

The writer quotes from the following authorities in regard to the unsanitary conditions of cesspools.

"Sparkling water may not be pure. It may contain typhoid germs. The filtration of sewage effluent does not purify it although it may clarify it. It requires the action of oxygen and light to render sewage harmless."—BURTON T. ASHLEY.

"It is hopeless to depend upon the purifying influence of intervening soil to protect the wells from cesspool fouling, because soil filtraton, in order to be effective must be intermittent."—MASON.

"The cesspool is a relic of medieval shiftlessness and carelessness for which no excuse can be offered."—DR. BASHORE.

"The privy or cesspool is walled with loose stone so that the liquid waste may leak through them into the surrounding soil. The result of this is a gradual increasing pollution of the soil and often a neighboring spring or well becomes so contaminated as to spread disease."—PROF. MERRIMAN.

THE SEPTIC TANK.

The modern septic tank, sometimes called a scum tank or putrefaction tank, consists essentially of a water tight chamber of suitable capacity, through which the sewage flows slowly, and almost continuously, the inlets and outlets being submerged to prevent an undue disturbance of the surface scum.

Countless numbers of bacteria harbored in the surface scum and living upon the solids in the sewage, cause its liquefaction. All solids settle to the bottom of the tank from which they are removed at frequent intervals.

Septic Tank Effluents.—While the liquid waste from the septic tank contains but little solid matter, it is highly charged with putrescible matter in solution, and the liquid gives off bad odors, particularly on warm or damp days. It cannot be sufficiently emphasized that the septic tank process is only a preliminary process of sewage treatment, that the waste from septic tanks are neither clarified nor purified, that they contain all the dissolved organic substances which are the chief causes of contamination of lakes and streams, and that a further purification in most cases is necessary.

Operation of Septic Tanks.—No septic tank shows good results when first put in operation. It is necessary that the process be carried on for several weeks before it becomes efficient. The claims that all suspended impurities are liquefied and that there will be no increase in the deposit of solids or in the scum in a septic tank have not been realized. On an average only from thirty to fifty per cent of the suspended solid matter is destroyed, partly by liquefaction and partly by changing them into gas.

Capacity of Septic Tanks.—The capacity of the septic tank should be made in size about three-fourths the daily volume of the sewage. Otherwise the tank acts as a mere settling chamber. On the other hand the tank should not be too large, as the sewage remains too long in the tank. By the use of two tanks in series the capacity of each tank may be reduced.

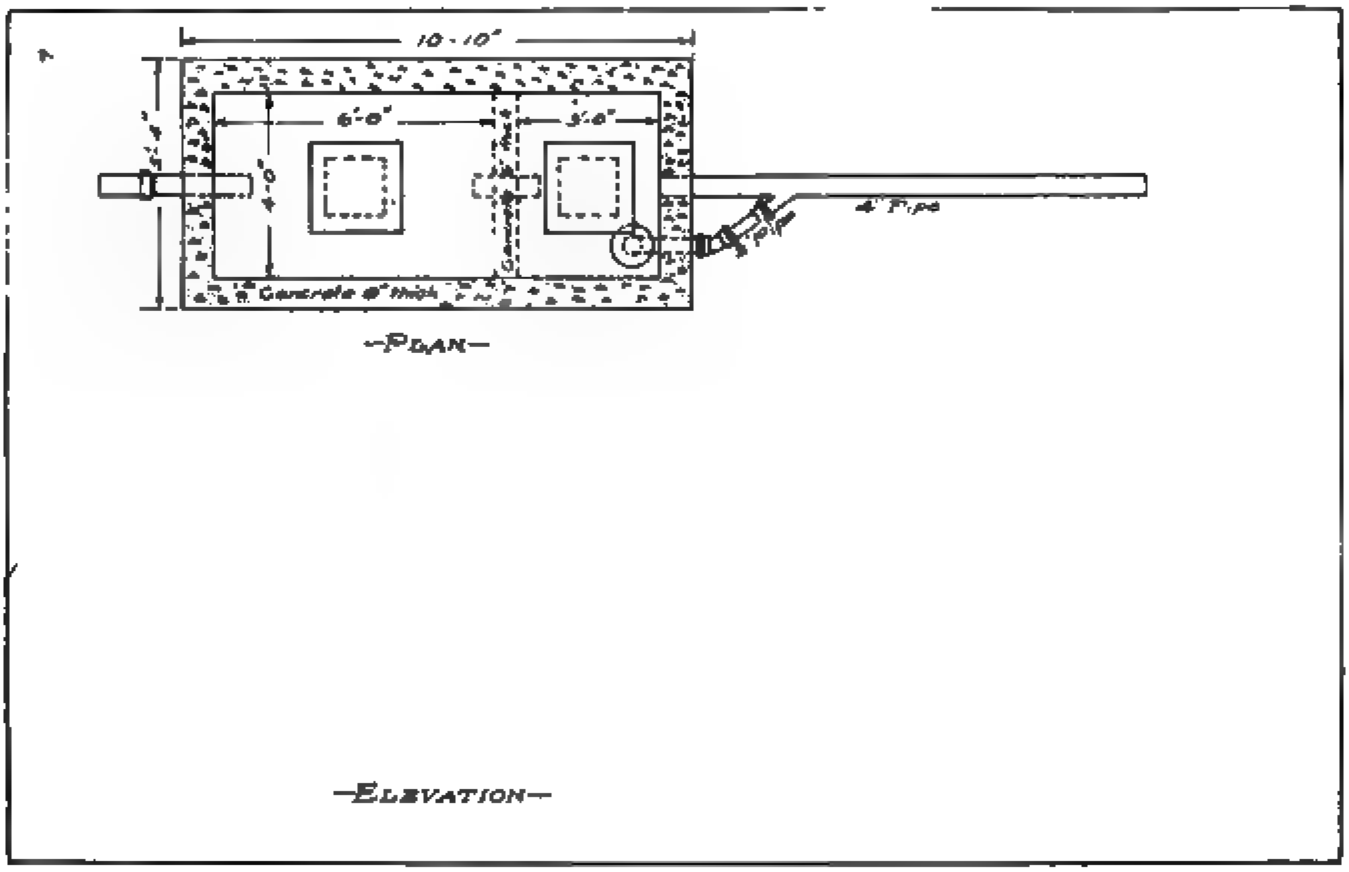
Open and Closed Septic Tanks.—For isolated buildings it is preferable to use covered tanks, notwithstanding the fact that open tanks have been found to be quite satisfactory. Reasons for this are: that bad odors are confined within the tank; the sewage scum is concealed from

sight; the surface of the sewage in the tank is protected from wind, rain and snow; but most important of all, the probable infection of food in the house by flies is prevented.

Small Concrete Septic Tank.—Fig. 2 shows a concrete septic tank which is designed large enough to provide for the sewage disposal of a family of six.

The tank operates as follows: Sewage enters tank "A" through a four-inch inlet pipe from the house. A heavy scum will form over the surface of the liquid, and beneath this scum the sewage is liquefied by

FIG. 2.



Small Concrete Septic Tank.

the action of the bacteria which develop or grow in the surface scum. For the successful growth or culture of these bacteria, the scum must not be frequently broken or disturbed, hence the inlet pipe is made to discharge below the surface of the liquid. For the same reason the overflow pipe from tank "A" to tank "B" is extended below the surface to about the middle of tank "A" where the liquefaction of the sewage is most complete.

In the sludge discharge pipe provision is made for cleaning out the sludge from the settling tank without putting it out of service, and, furthermore, provision is made for the discharge of the contents of the tank during a time when it may be found necessary to repair the siphon.

After passing through the flush tank the sewage may be discharged directly into a creek or a running stream. Under most conditions, if a running stream were not available, the effluent may be discharged

into a ditch or other drainage branch which should be seventy five or one hundred yards from the house. No offense from odor will ordinarily be given from such a system of disposal, as there will usually be enough rain during the year to flush the small creek or ditch into which the waste enters.

When the effluent is discharged direct into a running stream of sufficient flow the tank "B" may be omitted. If the waste is treated by subsurface irrigation, then the flush tank "B" should always be used in order to have the sewage delivered intermittently. If the flow be continuous upon the ground then sufficient time is not given to allow the air to enter the soil, and consequently it soon becomes water-logged.

A six-inch partition should separate settling tank "A" from flush tank "B." The liquefied sewage flows from tank "A" from flush from which it is removed by means of an automatic siphon, which is so designed that it will discharge when the sewage reaches a certain height in the flush tank. This siphon should be so arranged that it will discharge the liquid twice every twenty-four hours. This siphon action will take place when the tank is receiving a flow of three hundred and sixty gallons per day.

To provide for the entrance of air into tank "B," which is necessary for the successful operation of the siphon, and also to provide for an overflow of the sewage in case the siphon becomes clogged and refuses to discharge the contents of tank "B," an overflow pipe is connected to the main discharge pipe as shown in Fig. 2.

A valve is placed in the bottom of the flush tank "B" to provide for the removal of sediment which in time may collect there.

The cost of the above septic tank, not including labor is as follows:

Cement, 22 sacks at 40c per sack	$ 8.80
175 ft., 4" V. C. pipe at 8c per foot	14.00
10 ft., 3" V. C. pipe at 6c per foot	.60
Automatic siphon	15.00
Incidentals	5.00
Total	$ 43.40

As will be noted above no estimate of the cost of sand or gravel has been made. In most farming communities this may be obtained from creeks or branches nearby at the expense of hauling.

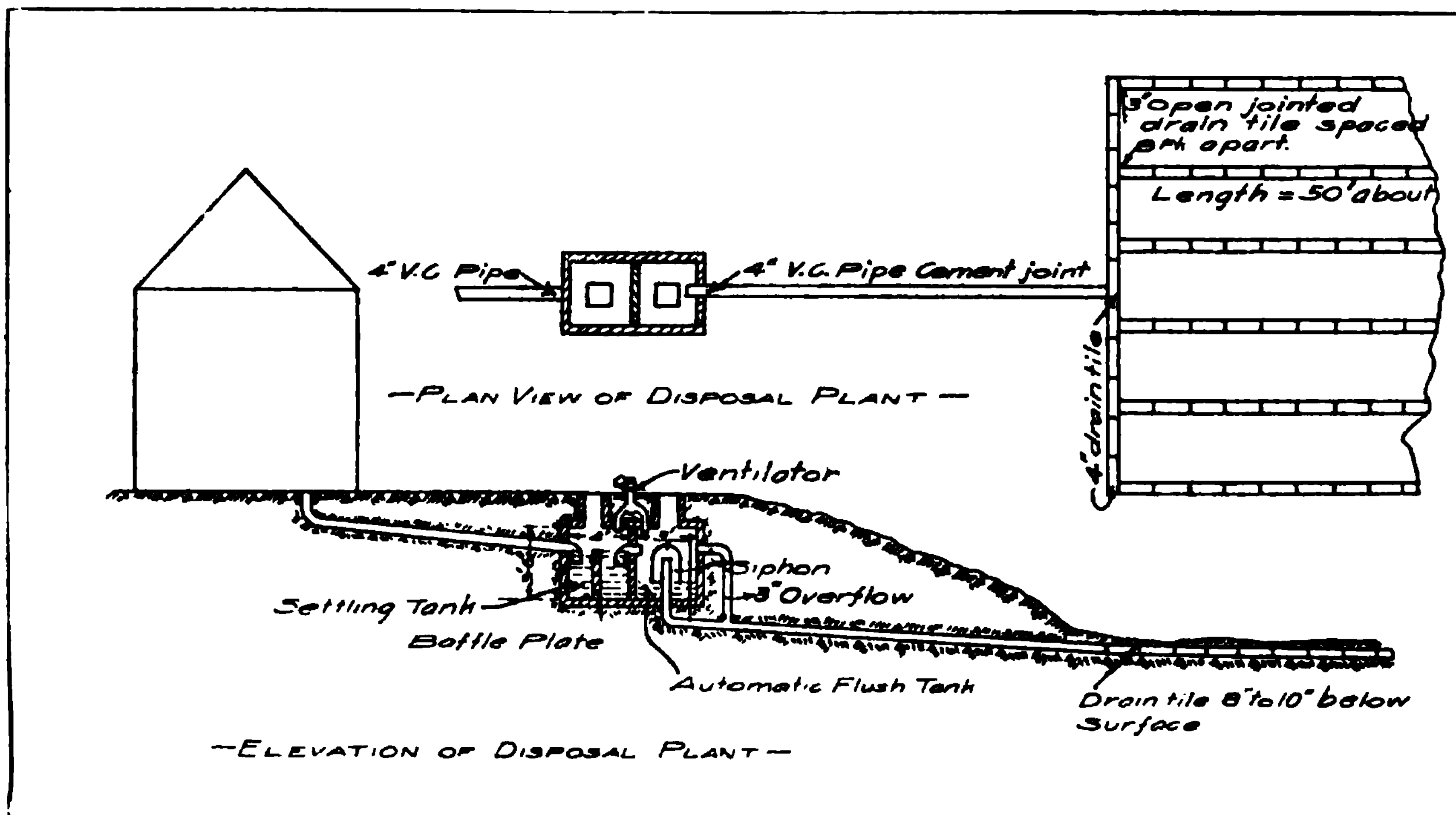
SUBSURFACE DISPOSAL OF SEWAGE.

In septic tank disposal sewage systems, as in all others of whatever nature they may be, some provision must be made for the effluent after it leaves the tank. If it is allowed to flow out upon the ground continually a nuisance will soon be created, which may endanger health.

In the absence of running streams into which to empty it, some other means of disposal must be resorted to. Perhaps the one of universal application is the *subsurface disposal* scheme. This plan may be successfully used whether the ground be level or sloping. In fact it is about the only method that may be used in a flat country.

Subsurface disposal means the disposal of the liquid sewage through a system of open-jointed drain tile laid from eight to twelve inches below the surface of the ground. The open joints should be from one-fourth to one-half inch apart, covered with some material to prevent loose earth from falling back into the pipe during the backfilling of the ditch. The length of the drain pipe will depend upon the amount of sewage and character of the soil. An intermittent discharge is essential, hence

FIG. 3.



Subsurface Disposal Plant.

the necessity of an automatic siphon. For the lateral drains a three-inch tile is ordinarily used.

It is evident that such a system of disposal requires the effluent to be a liquid, otherwise the drain tiles would soon become clogged and stop the operation of the plant.

Design of the Subsurface Disposal Plant.—Fig. 3 shows the arrangement of a typical subsurface disposal system. The plan view illustrates the method of arranging the drain tile. The distance of the septic tank from the house is about one hundred feet, and from the septic tank to the disposal field approximately one hundred feet. Local conditions will govern entirely as to the location of the tank and the disposal ground. In no case should the tank be closer to the house than one hundred feet.

Construction.—The pipe connecting the septic tank to the house should be a four-inch vitrified clay pipe, with bell and spigot joints carefully cemented. The four-inch pipe connecting the two tanks is to be arranged as shown in the drawing, Fig. 3.

The pipe line connecting the flush tank with the disposal ground is to be a four-inch V. C. pipe with cemented joints, and laid to a grade of at least one-fourth inch to the foot.

The main transverse drain tile should be four inches in diameter laid level with cemented joints. It is necessary that this tile be laid level in order to secure an equal distribution of the sewage to the laterals. The lateral drains should be three inches in size, laid in rows about fifty feet long and eight feet apart, and laid to the grade of one inch in twenty-five feet.

For a family of six people from 150 to 200 feet of drain tile will be necessary in a loose soil. In a compact clay soil, a much greater length will be needed, probably 300 to 400 feet.

Septic Tank.—The septic tank shown here consists of a settling tank and a flush tank provided with an automatic siphon. For the details of construction see Fig. 2.

Approximate Cost of Septic Tank.

Cement, 22 sacks at 40c	$ 8.80
100 ft. of 4″ V. C. pipe at 8c	8.00
10 ft. of 3″ V. C. pipe at 6c	.60
40 ft. of 4″ drain tile at 4c	1.60
150 ft. of 3″ drain tile at 3c	4.00
Automatic siphon	15.00
Incidentals	5.00
Total	$43.00

SURFACE DISPOSAL OF SEWAGE.

The surface disposal problem for sewage is solved in various ways. As in the case of the subsurface disposal scheme, it is essential that the sewage be discharged upon the surface of the ground intermittently. Such an arrangement gives time for the purification of the soil, which would soon become water-logged if the flow of sewage upon it were continuous.

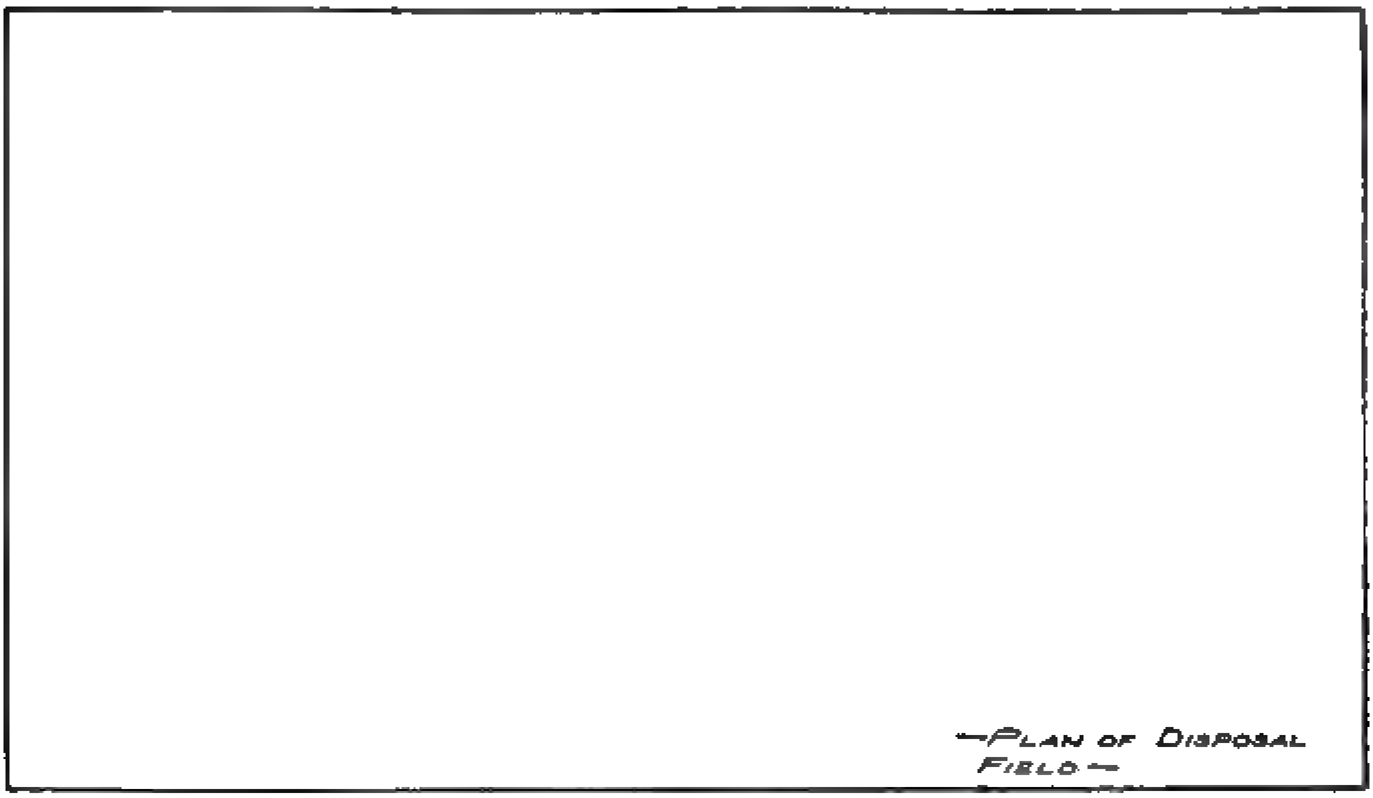
Fig. 4 shows a typical surface disposal plant. The operation of the septic tank used is identical with that of Fig. 2, the only change being in the method of the final disposal of the discharged sewage. See Fig. 2 for the details of the construction of the septic tank.

The Disposal Field.—This plot of ground may be a small patch of cultivated land with a growing crop, such as corn, or it may be a piece

of meadow or pasture land. A plot containing 2500 square feet will be ample to take care of the sewage from a family of six. This plot of ground should be at least 200 feet from the house or well, or any source of water supply. Upon reaching the disposal field the sewage empties into a ditch about one foot wide and four inches deep running at right angles to the disposal pipe from the septic tank.

Distributing Ditches.—The distributing ditches may be from four feet to six feet apart, and four inches deep by eight inches wide. Their

FIG. 4.



Surface Disposal Plant.

length will depend upon the size of the available disposal plot. There should be a sufficient number of ditches to quickly and equally distribute the sewage over the field.

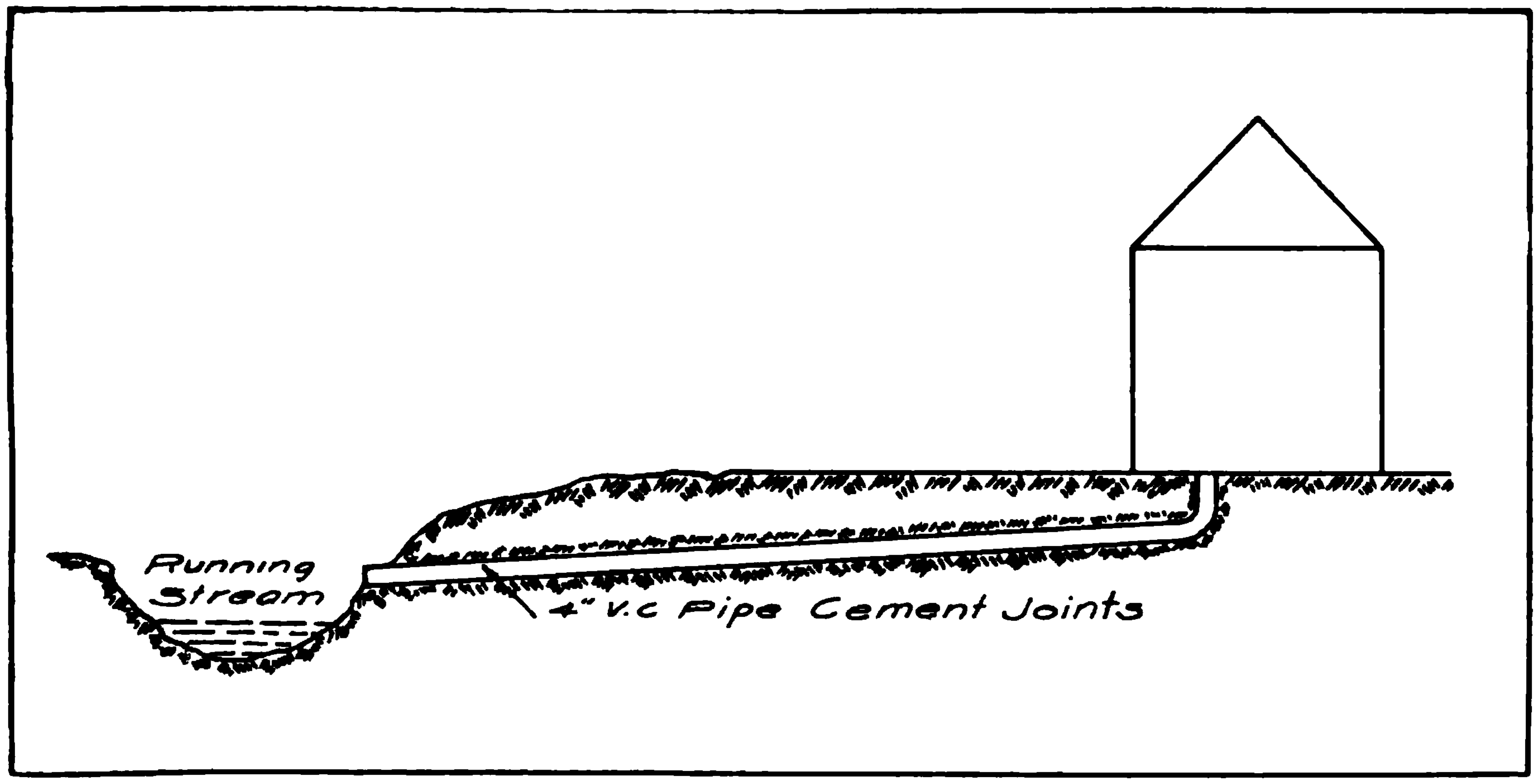
Estimated Cost.

Cement, 22 sacks at 40c	$ 8.80
100 ft. V. C. pipe at 8c	8.00
10 ft. V. C. pipe at 6c	.60
Automatic siphon	15.00
Incidentals	5.00
Total	$37.40

DIRECT DISPOSAL SYSTEM.

In some cases it may be advisable to dispose of the sewage directly into a running stream, but this plan is not to be generally recommended as the best. The danger is that the water farther down the stream sometimes used for drinking purposes may become contaminated, or the supply water for stock may be so fouled as to become unfit for use. If the flow of the stream be large, the dilution will be so great that little danger will occur from its contamination by the sewage of a single farm house. Disease germs may be transmitted for a distance of several miles, hence there is always danger in using for drinking purposes any water from a river into which sewage empties.

FIG. 5.



Direct Disposal Plant.

Fig. 5 shows an arrangement for the disposal of sewage direct into a stream. The discharge pipe should have a uniform slope of about one foot in twenty-five feet to insure its proper flushing.

Estimating the Cost.—The cost will obviously depend upon the distance of the house from a nearby creek. The disposal pipe should be a four-inch vitrified clay pipe, and will cost eight cents per foot. The cost may be estimated for any specific design in hand from the general cost data given below, including cement, sewer piper, drain tile, and concrete.

General Cost Data.—

Cement 40c per sack, net.
Sewer pipe, 3", 6c per foot.
Sewer pipe, 4", 8c per foot.
Sewer pipe, 6", 11c per foot.
Sewer pipe, 8", 20c per foot.

Elbows, 1/4, 1/8, and 1-16 bend.—

3″ 30c each.
4″ 35c each.
6″ 45c each.
8″ 60c each.

Y's and T's.—

3″ 35c each.
4″ 45c each.
6″ 70c each.
8″ 90c each.

Traps.—

3″ 65c each.
4″ 75c each.
6″ $1.00 each.
8″ $1.60 each.

Drain Tile.—

3″ 3c per foot.
4″ 4c per foot.
6″ 6c per foot.

Concrete.—On an average concrete for the above construction will cost from five to seven dollars per yard where it is necessary to hire all labor and buy all materials. One barrel of cement (about four sacks) will in general make one cubic yard of concrete consisting of a 1:2½:5 mixture.

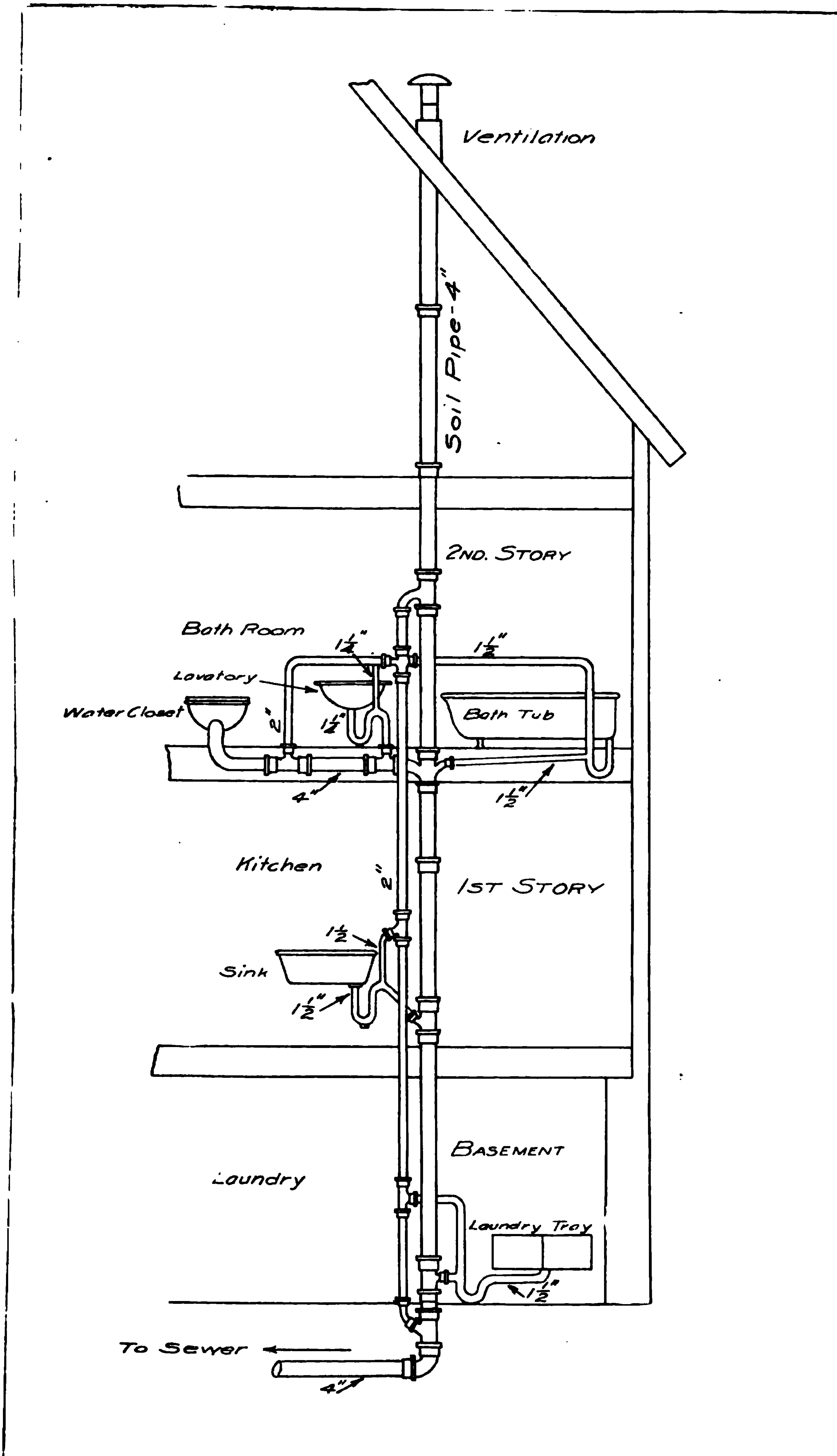
PLUMBING.

Fig. 6 shows the plumbing of the bath-room, kitchen and laundry of a modern house. The plumbing necessary for carrying the sewage to the main sewer outside of the house is also shown in the drawing. It will be noted that the system is fully vented so that no trouble will be had from the escape of sewer gas into the house.

The fixtures usually placed in the bath-room are the bath tub, wash basin, and the water closet; in the kitchen, a sink, and in the basement a laundry tray or tub.

The main ventilation or soil pipe, as it is commonly called, should pass upward through the roof to the open air. Its purpose is to relieve the gas pressure which might otherwise force the traps and enter the house. The top of the soil pipe should be covered with a cap to prevent the entrance of rain or snow.

FIG. 6.



Plumbing System for Sewage Disposal.

Cost.—The cost of the plumbing will depend upon the quality of the fixtures installed. For a two-story seven-room house fitted with first-class plumbing and fixtures throughout, the cost will be about $165. This cost item includes the following: Bath tub, wash basin, water closet, kitchen sink, laundry tub, a forty gallon hot water heater in the kitchen, all the necessary water piping to bath room, laundry and kitchen, and all the necessary drain tile and sewer pipe completely installed ready to connect with the main sewer located outside a few feet away from the house.

The expense item of $165 mentioned above includes the cost of both labor and material. We may add to this sum $50 for the septic tank and sewer pipe outside of the house, giving a total cost of $215. This estimate does not include the cost of a supply tank for water, nor the cost of putting in the water supply pipes. The water supply is described in a bulletin: "Water Supply for Country Homes," which may be obtained by addressing the Director, Missouri Engineering Experiment Station, Columbia, Missouri.

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THE HEATING VALUE AND PROXIMATE ANALYSES OF MISSOURI COALS

BY

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PAUL SCHWEITZER

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The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and two research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

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HEATING VALUES AND PROXIMATE ANAYLSES OF MISSOURI COALS.

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DR. PAUL SCHWEITZER, Professor of Chemistry (1872-1909).

Introductory Note:—This bulletin is a reprint of a report upon the properties of Missouri coals made about ten years ago by Prof. C. W. Marx, then Professor of Mechanical Engineering, University of Missouri, in collaboration with Dr. Paul Schweitzer, who was at that time Professor of Agricultural Chemistry. As this report contains information relative to the characteristics of Missouri coals not published elsewhere it has been decided to republish it in an Engineering Experiment Station Bulletin in order that it may continue to be of value and available for the use of the citizens of the State.

During the fall and winter of 1900-1901 the writer undertook a systematic investigation of the coals mined in Missouri. All the samples, save one, were cut from the face down through the entire thickness of the vein. A sample of about forty pounds thus collected from each mine was carefully sampled down to fill a Mason quart jar which, properly sealed, was taken without delay to the Experiment Station Laboratory where all analytical work including heat values by the bomb calorimeter was done. The calorimeter results have been calculated on the basis of the coal as taken from the mine to be burned.

The value of a fuel depends upon the number of heat units that it will produce and is usually measured in number of pounds of water that one pound of such fuel will evaporate or convert into steam. This is called its calorific value and is really the value for steam boiler purposes obtained per pound of coal.

Although coal is the most important mineral of Missouri, no thorough and complete investigation of the calorific values of her coals has hitherto been made, so far as is known. The two Departments of the State University above mentioned have undertaken, therefore, such an investigation and now print a report of the same. Professor Marx visited every mine mentioned, took the samples in person at the face, except in the case of sample No. 7. On account of the lateness of the hour and the condition of the entrance to the mine this sample was picked from a car that seemed to have been loaded during the day.

EXPLANATION OF TERMS.

A heat unit is the quanity of heat required to raise the temperature of one pound of water, at its maximum density, one degree Fahrenheit. The expression from and at 212 degrees F. means that the water

I.—TABLE SHOWING CALORIFIC VALUE OF MISSOURI COALS.

Rank.	Name of Mine.	County.	Location.	Thickness of vein in inches.	Heat units per pound of coal.	Pounds of water evaporated from and at 212° F. per lb. of coal. Boiler efficiency 60%.
1	No. 8, Western Coal Co.	Barton	Near Minden Station	36	13763	8.55
2	No. 3, Weir Coal Co.	Barton	Near Vernon Station	36	13759	8.55
3	Brush Creek Coal Co. Upper Vein	Jackson	3 miles Southeast of Kansas City	16	13710	8.52
4	No. 14, Central Coal and Coke Co.	Bates	5 miles South of Rich Hill	60-66	13500	8.38
5	Rush Coal Co.	Bates	5 miles South of Rich Hill 1½ miles West of previous one	42	12824	7.96
6	Keene	Boone	4½ miles North of Columbia	44	12780	7.94
7	Thompson	Henry	1 mile East of Deepwater		12757	7.92
8	Henry	Boone	Switzler	42	12492	7.76
9	Cooper Creek Coal Co.	Henry	3½ miles Southeast of Deepwater	32-42	12326	7.66
10	Kingston	Caldwell	1 mile North of Kingston	12-18	12292	7.63
11	Caldwell Coal Co.	Caldwell	2 miles East of Hamilton	18-20	12115	7.52
12	Bowen Bros.	Henry	½ mile Northeast of Louis Station	30	12093	7.51
13	Watkins	Henry	1½ miles Southeast of Clinton	24	12090	7.51
14	Excelsior	Lafayette	½ mile West of Higginsville	16	12010	7.46
15	Vernon Coal Co.	Bates	2½ miles Southeast of Rich Hill	36-60	11978	7.44
16	Marceline Coal Co.	Linn	½ mile South of Marceline	28	11939	7.41
17	Murlin Coal Co.	Adair	½ mile North of Stahl	48	11854	7.36
18	No. 15, Rich Hill Coal Co.	Bates	2 miles South of Rich Hill	48	11834	7.35
19	Edmonds	Lafayette	¼ mile East of Waterloo	18	11829	7.35
20	No. 6, Farmers' Consolidated	Lafayette	1 mile West of Higginsville	16	11824	7.34
21	No. 66, Kansas & Texas Coal Co.	Macon	3 miles South of Bevier	56	11769	7.31
22	Silver Creek Coal Co.	Lafayette	¼ mile West of Waverly Station	48	11764	7.30
23	Elliott Coal Co.	Randolph	Elliott Station	48	11676	7.24

24	Buckhorn Coal Co.	Lafayette	1 mile West of Waverly Station	48	11643	7.23
25	No. 10, Morris Coal Co.	Randolph	1 mile East of Huntsville	48	11642	7.23
26	No. 70, Kansas & Texas Coal Co.	Macon	4½ miles Southwest of Excello	54	11626	7.22
27	Murlin Coal Co.	Ray	Fleming Station	22	11583	7.19
28	Salt Fork Coal Co.	Lafayette	½ mile East of Corder	22	11580	7.19
29	Jones & Davis	Randolph	3 miles West of Moberly	48	11574	7.19
30	Brush Creek Coal Co. Lower Vein	Jackson	3 miles Southeast of Kansas City	24	11524	7.16
31	No. 1, Higbee	Lafayette	½ mile West of Higbee	44-48	11522	7.15
32	Labor Exchange	Lafayette	1¼ miles West of Wellington	18	11492	7.14
33	No. 1, J. C. McGrew	Lafayette	3½ miles West of Lexington	22	11395	7.08
34	Emporia	Putnam	1¼ miles North of Unionville	36	11390	7.07
35	No. 61, Kansas & Texas Coal Co.	Macon	2 miles Southwest of Bevier	51	11372	7.06
36	Richmond & Camden Coal Co.	Ray	1 mile West of Camden	20	11331	7.04
37	No. 11, Richmond & Camden Coal Co.	Ray	1 mile West of Richmond	24	11322	7.03
38	No. 8, Mendota Coal Co.	Putnam	½ mile South of Mendota Station.	36	11274	7.00
	Missouri City Coal Co.	Clay	Missouri City	22	11274	7.00
39	No. 14, Richmond & Camden Coal Co.	Ray	¼ mile South of Richmond	24	11250	6.99
40	Corder Coal Co.	Lafayette	¾ mile West of Corder	22	11233	6.98
41	Glen Oak, Lexington Coal Co.	Lafayette	4 miles Northeast of Lexington	24	11220	6.97
42	Valley Mine, Lexington Coal Co.	Lafayette	1½ miles South of Lexington	22	11209	6.96
43	North Western Coal Co.	Macon	1 mile South of Bevier	42-48	11191	6.95
44	No. 2, Higbee	Lafayette	2 miles East of Higbee	42	11147	6.92
45	Dover Coal Co.	Lafayette	1 mile East of Dover Station	18	11018	6.84
46	Rombauer	Adair	½ mile West of Novinger	43	10877	6.77
47	Carter	Lafayette	1½ miles East of Wellington	20	10770	6.69
48	Graddy-Lexington Coal Co.	Lafayette	3 miles West of Lexington	20	10759	6.68
49	Grundy Coal Co.	Grundy	½ mile Southeast of Trenton	18	10704	6.65
50	J. B. Seitz	Lafayette	¾ mile West of Waterloo	18	10664	6.62
51	No. 2, Mendota Coal Co.	Putnam	2 miles Southeast of Mendota Sta.	34	10623	6.60
52	Mayview Coal Co.	Lafayette	Near Mayview Station	18	10458	6.50
53	Blackbird	Putnam	3 miles Northeast of Unionville	34	10437	6.48
54	Lingo	Macon	Opposite Lingo Station	36-42	10224	6.35

is taken in at a temperature of 212 degrees Fahrenheit and evaporated at atmospheric pressure. Thus all the heat is used to evaporate the water. This is merely an arbitrary standard used in boiler-testing.

In table I, the column headed heat units per pound of coal is the maximum number of heat units that one pound of coal will yield when burned in a furnace where there are no losses of any kind. The number of pounds of water that a pound of coal will evaporate from and at 212 degrees F. depends upon the efficiency of the boiler and furnace. The efficiency of boilers in our western states with the ordinary furnace and setting generally varies from 50 per cent to 60 per cent, but in a great many cases it is far below 50 per cent. With mechanical stokers, uniform duty, well designed boiler, and well designed furnace, an efficiency of 70 per cent is easily maintained. Assuming a boiler efficiency of 60 per cent the last column in table I was computed. It shows the number of pounds of water that one pound of the various coals would evaporate under favorable conditions with such an efficiency (60 per cent), the water being taken in at 212 degrees F. and evaporated at atmospheric pressure.

Table I shows the rank of the coals arranged according to their calorific value.

Table II shows the same coals according to their rank as in table I with their proximate analyses. These proximate analyses were made according to accepted methods. All coals were analyzed and tested in duplicate. Since some of the coals showed the presence of gypsum, it was deemed best not to subtract the sulphur found from the volatile matter and from the fixed carbon as is usually done.

The last column in table II shows how far the calorific value of a coal is dependent upon the amount of the volatile matter and fixed carbon. A study of this column will show that with few exceptions the sum of these two percentages seems to determine the rank of the coal, the same as the calorific value did in table I.

It is not claimed that the calorific values, as obtained and tabulated on a basis of 60 per cent boiler efficiency, are the real measures of the heating values of the various coals, but merely indices thereof and aids to a comparative estimate only.

The only way to obtain these real values for different coals at any given steam plant is to burn equal quantities of them under the same boiler, all conditions being the same for all the tests. The coal that is most economical for one steam plant under its peculiar conditions is not necessarily the most economical for another, on account of the furnace, grate area, etc. In addition to testing the coals by burning them under a boiler and determining the number of pounds of

water evaporated per pound of coal, a record of the proximate analyses should be kept, in order to establish a standard of quality in making future purchases. Such a record will show that coals, ranging between certain percentages in volatile matter, moisture, fixed carbon, ash, and sulphur, are the more economical.

Sulphur occurs in coals as sulphide of iron, commonly known as iron pyrites, and sulphate of lime, usually known as gypsum. The sulphur is an index of the clinker-forming property of a coal since it assists in the fusing of the ash.

The heating value of a coal, depending chiefly upon the per cent of fixed carbon, and less upon the per cent of volatile matter, is materially affected by the per cent of ash, moisture and sulphur in the form of gypsum. These precentages vary with individual mines and with different places in the same mine. The amount of ash in the commercial product depends in great measure upon the care taken at the mines in cleaning it before shipment. The evaporating capacity of a boiler having a given number of square feet of heating surface and grate area, depends primarily upon the number of heat units generated in the furnace. The greater the number of heat units a given coal produces per pound, the greater will be the number of pounds of water evaporated per pound of coal burned under this boiler.

If a coal contain a large per cent of moisture and hydrogen, not only will the number of heat units derived be reduced by evaporating this moisture present and formed, but also by heating this aqueous vapor to the temperature of the chimney, all of which heat escapes and in no way serves to furnish heat to the boiler.

If a coal is high in the percentage of ash, not only will its heat value be diminished, but the quantity of ash and clinker resting upon the grate bars will tend to reduce the draft area and hence will prevent perfect combustion. Moreover the gases which would otherwise burn and produce heat with a proper air supply are in danger of escaping unburned. A coal high in content of ash demands a stronger draft and a larger grate area than one with a lower content. A boiler designed with a furnace to burn a coal with a low percentage of ash will give very unsatisfactory results with a coal having a large percentage of ash, and vice versa. In other words, a boiler furnace should be designed as nearly as possible for a given quality of coal, from which it is evident that with a given grate area the quality of the coal determines in a great measure the capacity and economy of a boiler.

II.—TABLE OF PROXIMATE ANALYSES OF MISSOURI COALS.

Rank.	Name of Mine.	Water Per cent.	Volatile matter per cent.	Fixed carbon per cent.	Ash per cent.	Sulphur per cent.	Volatile matter plus carbon.
1	No. 8, Western Coal Co.	2.35	35.73	53.72	8.20	4.10	89.45
2	No. 3, Weir Coal Co.	3.62	34.40	53.98	8.00	4.02	88.38
3	Brush Creek Coal Co.	10.30	40.04	45.35	4.31	2.35	85.39
4	No. 14, Central Coal Co., Upper Vein	2.02	40.80	46.39	10.79	6.57	87.19
5	Rush Coal Co.	4.07	41.05	43.22	11.66	3.38	84.27
6	Keene	6.17	40.83	45.04	7.96	3.72	85.87
7	Thompson	8.95	34.75	51.28	5.03	1.11	86.03
8	Henry	9.62	38.50	45.63	6.25	2.78	84.13
9	Cooper Creek Coal Co.	7.24	34.60	48.10	10.06	2.64	82.70
10	Kingston	10.63	38.58	44.03	6.76	2.54	82.61
11	Caldwell Coal Co.	9.26	36.69	43.56	10.49	3.61	80.25
12	Bowen Bros.	6.65	40.27	40.68	12.40	4.67	80.95
13	Watkins	8.10	36.13	45.02	10.75	4.72	81.15
14	Excelsior	10.25	36.10	44.69	8.96	3.54	80.79
15	Vernon Coal Co.	6.34	35.89	44.47	13.30	4.81	80.36
16	Marceline Coal Co.	9.45	33.25	47.27	10.03	5.73	81.52
17	Murlin Coal Co.	14.78	39.10	42.44	3.68	2.16	81.54
18	No. 15, Rich Hill Coal Co.	5.88	35.20	44.72	14.20	4.83	79.92
19	Edmonds	9.55	35.23	46.42	8.80	3.15	81.65
20	No. 6, Farmers' Consolidated	11.95	36.14	44.70	7.21	2.57	80.84
21	No. 66, Kansas & Texas Coal Co.	12.00	39.10	41.83	7.07	3.44	80.93
22	Silver Creek Coal Co.	8.34	37.68	41.34	12.64	5.28	79.02
23	Elliott Coal Co.	11.15	36.32	42.77	9.76	3.55	79.09
24	Buckhorn Coal Co.	8.58	38.20	42.04	11.18	4.90	80.24
25	No. 10, Morris Coal Co.	9.90	31.73	47.33	11.04	2.86	78.06
26	No. 70, Kansas & Texas Coal Co.	10.20	36.26	43.16	10.38	4.47	79.42

27	Murlin Coal Co.	13.07	37.85	41.66	7.42	1.92	79.51
28	Salt Fork Coal Co.	11.88	35.76	43.64	8.72	3.76	79.40
29	Jones & Davis	11.05	36.87	41.65	10.43	6.56	78.52
30	Brush Creek Coal Co., Lower Vein	7.85	33.18	44.17	14.80	5.05	77.35
31	No. 1, Higbee	10.00	29.99	50.77	9.24	3.57	80.76
32	Labor Exchange	12.31	35.91	43.58	8.20	1.71	79.49
33	No. 1, J. C. McGrew	15.02	34.20	43.20	7.58	2.97	77.40
34	Emporia	17.48	36.01	42.40	4.11	2.38	78.41
35	No. 61, Kansas & Texas Coal Co.	12.12	37.43	41.30	9.15	3.74	78.73
36	Richmond & Camden Coal Co.	9.83	37.93	42.99	9.25	3.21	80.92
37	No. 11, Richmond & Camden Coal Co.	11.97	36.36	41.65	10.02	4.36	78.01
38	No. 8, Mendota Coal Co.	17.29	37.19	41.43	4.09	2.66	78.62
	Missouri City Coal Co.	12.45	34.48	42.44	10.63	2.95	76.92
39	No. 14, Richmond & Camden Coal Co.	10.20	36.75	41.20	11.85	5.87	77.95
40	Corder Coal Co.	9.90	35.08	43.05	11.97	4.78	78.13
41	Glen Oak, Lexington Coal Co.	14.39	35.00	44.58	6.03	2.01	79.58
42	Valley Mine, Lexington Coal Co.	13.75	35.30	42.40	8.55	2.22	77.70
43	Northwestern Coal Co.	11.00	31.77	45.74	11.49	4.28	77.51
44	No. 2, Higbee	10.84	28.28	49.30	11.58	5.68	77.58
45	Dover Coal Co.	12.33	34.53	42.05	11.09	4.56	76.58
46	Rombauer	12.12	30.10	44.20	13.58	3.52	74.30
47	Carter	11.56	32.93	42.10	13.41	3.50	75.03
42	Graddy, Lexington Coal Co.	12.33	31.55	42.64	13.48	3.94	74.19
49	Grundy Coal Co.	10.07	31.62	43.90	14.41	5.43	75.52
50	J. B. Seitz	10.13	32.23	41.74	15.90	7.56	73.97
51	No. 2, Mendota Coal Co.	17.59	34.11	39.85	8.45	3.21	73.96
52	Mayview Coal Co.	10.50	32.43	40.63	16.44	3.48	73.06
53	Blackbird	13.46	34.88	38.36	13.30	4.29	73.24
54	Lingo	10.16	29.78	41.26	18.80	7.33	71.04

Table III is a summary of tests of various Illinois coals ranked according to the sum of the percentages of fixed carbon and volatile matter.

It seems to be shown in table II that the amount of the fixed carbon and volatile matter puts the various coals, with a few exceptions, in the same order as does the calorific value. Hence it was thought well to arrange the Illinois coals so as to compare them with coals from Missouri according to the amount of fixed carbon and the volatile matter, as the calorific values of Illinois coals were not available. A careful study of tables II and III will show that Missouri coals compare well with those from Illinois.

THE DETERMINED DISTRIBUTION OF COALS IN MISSOURI.

By C. F. Marbut, Professor of Geology.

The accompanying map shows the distribution, so far as known, of the more important coal beds of Missouri. The continuous line along the border of the shaded area indicates that the limit of the coal bed in this direction is determined. Where there is no sharp border to the shaded area it indicates that the coal bed may extend further.

The Bevier coal bed is the thickest and has the widest distribution. Over the area outlined on the map it has an average thickness of nearly four feet. The thickness within the area of any one mine or mining region is essentially uniform, and it is rarely interrupted by faults. "Horses" or "clay rolls" occur occasionally, but not abundantly enough to cause serious interference with mining.

The roof is a sandy shale, sometimes occurring as a sandstone. It is solid enough to furnish a safe roof when properly supported, and in some places it is secure enough for long-wall mining.

The coal bed rests on a layer of underclay with an average thickness of about a foot. This is usually taken up in the roadways, since it is easier to do this than to "brush" down an equal thickness of the shale. The clay rests on a bed of limestone about five feet thick, which gives a solid foundation for the roadway. All through the southern end of this coal field the coal bed consists of two layers of coal, with a one-inch parting of pyritiferous shale. North of Adair county this shale seems to thicken and finally to become thick enough to separate the bed into two independent beds with several feet of shale between them.[1]

The Lexington coal bed is shown on the map to cover a large area along the Missouri river east of Kansas City. It may be said in passing that the unbroken extent of this coal bed over the whole of the area shaded is not proved beyond question. There are mines, however, scattered over this area which operate coal beds of about the same thickness and character as the Lexington bed, and presumably they are the same. It is known to extend southward into Johnson county, but is too thin to be mined profitably under existing conditions. The thickness of the bed within the shaded area varies from sixteen to twenty-six inches. It is overlaid by two feet of black fissile shale,

(1) For the detailed geology of this coal bed in Randolph and Macon counties, see the Geology of the Huntsville Quadrangle in Vol. XII of the Reports of the Missouri Geological Survey and "The Bevier Sheet" in Vol. IX of the same reports.

III.—TABLE OF PROXIMATE ANALYSES OF ILLINOIS COALS.

Rank.	Shipper.	County.	Name.	Town or District.	Moisture.	Volatile matter.	Fixed Carbon.	Ash.	Sulphur.	Volatile matter plus Carbon.
‡ 1	New Kentucky Coal Co..		Big Muddy Lump		2.29	37.78	54.53	5.40	.94	92.31
† 2		Jackson...		Mt. Carbon...	6.1	24.7	66.5	2.7	......	91.2
† 3		Vermillion		Danville.....	4.8	43.7	45.4	5.2	......	89.1
‡ 4	Glenburn Coal Co.		Mine Run......		1.66	46.33	41.32	10.69	3.20	87.65
‡ 5	New Kentucky Coal Co..		Murphysboro....		3.71	36.25	50.30	9.74	1.50	86.55
† 6		Jackson...		Carbondale...	6.4	26.4	59.8	7.4	......	86.2
‡ 7	T. C. Loucks		Lump...........		3.54	43.44	42.71	10.31	3.89	86.15
† 8		St. Clair..		Heintz Bluff.	9.0	37.8	48.2	5.0	3.3	86.0
‡ 9	Du Quoin Union Coal Co.		Du Quoin Lump		3.85	37.39	48.54	10.22	1.86	85.93
‡ 10	New Kentucky Coal Co.		Big Muddy Nut		5.13	36.36	49.44	9.07	1.17	85.80
† 11		Vermillion		Danville.....	11.0	32.6	53.0	3.6	......	85.6
‡ 12	T. C. Loucks............		Pea.............		3.32	41.68	43.90	11.10	3.87	85.58
† 13		Peoria....		Peoria.......	3.2	36.1	49.2	11.4	......	85.3
† 14		Jackson...		Big Muddy..	6.4	30.6	54.9	8.3	1.5	85.2
‡ 15	Williamsville Coal Co. ..		Nut............		2.45	43.50	41.69	12.36	4.20	85.19
† 16		Fulton....		Cuba........	4.2	36.4	48.6	10.8	......	85.0
† 17		Jackson..		Big Muddy Odin	7.7	31.9	53.0	7.4	......	84.9
†		Marion...		Odin.........	6.1	34.0	50.9	9.1	......	84.9
‡ 18	Williamsville Coal Co. ..		Pea.............		2.65	42.25	42.62	12.48	3.70	84.87
† 19		La Salle..		Peru.........	6.6	37.2	47.2	9.0	......	84.4
‡ 20	Virden Coal Co.		Nut............		5.15	40.82	43.54	10.49	3.78	84.36
† 21		La Salle..		Streator.....	7.2	38.9	45.3	8.6	......	84.2
† 22		La Salle.		Streator.....	12.0	35.3	48.8	3.9	2.4	84.1
†		Perry....		Du Quoin ...	8.9	23.5	60.6	7.0	......	84.1
† 23		Sangamon		Riverton.....	6.4	35.4	48.4	9.8	......	83.8
† 24		Fulton...		Canton.......	3.5	37.0	46.7	12.8	......	83.7
†		Macon...		Niantic......	7.9	36.3	47.4	8.5	......	83.7

‡ 25	Gardner Wilmington		Mine Run......		7.90	45.95	37.60	8.55	2.93	83.55
† 26		Vermillion		Danville.....	5.6	37.1	46.4	10.9	......	83.5
† 27		La Salle		La Salle.....	8.2	39.4	44.0	8.4	......	83.4
†		Macoupin		Staunton.....	6.3	57.1	26.3	10.3	......	83.4
‡ 28	T. C. Loucks		Nut............		2.80	42.40	40.46	14.34	3.86	82.86
† 29		Macoupin.		Mt. Olive....	10.4	36.7	46.1	6.8	3.5	82.8
† 30		Sangamon		Loose's.......	10.7	37.6	45.1	6.6	2.4	82.7
† 31		Clinton...		Trenton......	13.3	30.4	52.0	4.3	0.9	82.4
† 32		Christian.		Pana.........	7.2	36.4	46.9	9.5	......	82.3
†		Logan....		Mt. Pulaski..	7.7	35.8	46.5	10.0	......	82.3
‡ 33	Black Diamond Coal Co.		Duff............		1.29	40.80	41.32	16.59	5.10	82.12
† 34		Sangamon		Barclay......	7.4	35.7	46.2	10.7	......	81.9
† 35		Grundy...		Morris.......	7.1	32.1	49.7	11.1	......	81.8
‡	Crerar Clinch & Co.		Pana Pea.......		4.70	41.20	40.60	13.50	3.68	81.8
‡ 36	Steck Coal and Coke Co.		Lump...........		4.30	42.53	39.25	13.92	2.59	81.78
† 37		McClean..		Bloomington.	4.1	36.4	45.2	14.7	......	81.6
‡ 38	T. C. Loucks		Duff............		1.24	39.04	42.21	17.51	4.31	81.25
† 39		Peoria....		Pottstown....	4.6	35.5	45.5	14.4	......	81.0
‡ 40	Riverton Coal Co.		Pea............		3.94	41.10	39.88	15.08	3.96	80.98
† 41		Fulton....		St. David....	2.0	34.6	46.2	17.2	......	80.8
† 42		Macoupin		Girard.......	9.7	34.4	45.8	10.1	3.5	80.2
†		Perry....		Du Quoin....	11.3	30.3	49.9	8.5	0.9	80.2
‡ 43	Wilmington Coal Co.		Washed........		5.14	39.30	40.88	14.68	3.30	80.18
‡ 44	Crerar Clinch & Co.		Illinois Central.		1.81	36.04	44.12	18.03	3.99	80.16
† 45		Fulton....		Farmington..	3.4	33.9	45.9	16.8	......	79.8
† 46		Logan....		Lincoln......	8.4	35.0	44.5	12.1	......	79.5
†		Marion...		Centralia.....	8.3	34.0	45.5	8.0	......	79.5
† 47		St. Clair.		St. Bernard..	14.4	30.9	48.4	6.4	1.4	79.3
‡ 48	Crerar Clinch & Co.		Du Quoin Pea..		3.15	38.94	39.99	17.92	3.18	78.93
‡ 49	Chicago & K. C. Coal		Duff............		1.15	37.89	41.02	19.94	3.36	78.91
† 50		Fulton....		Dunfermline.	2.5	32.9	45.6	19.1	......	78.5
‡ 51	Colfax Coal & Mining Co.		No. 2, Nut......		2.61	41.36	36.96	19.07	4.19	78.32
† 52		Peoria....		Edwards.....	1.9	34.5	43.6	20.0	......	78.1
† 53		Bureau....		Ladd.........	12.0	32.3	42.5	13.8	......	77.6

‡ These analyses were made by the Illinois Steel Company at their Chicago plant and were doubtless taken from cars in the coal company's yards, hence the low percentages of moisture.

† These analyses were made by various persons and are published in Kent's Steam Boiler Economy and were doubtless taken from the mines.

III.—TABLE OF PROXIMATE ANALYSES OF ILLINOIS COALS—Continued.

Rank.	Shipper.	County.	Name.	Town or District.	Moisture.	Volatile matter.	Fixed Carbon.	Ash.	Sulphur.	Volatile matter plus Carbon.
† 54		St. Clair..		Oakland......	8.3	34.4	43.1	14.2	4.4	77.5
† 55		Macoupin		Mt. Olive....	8.1	33.1	44.1	14.7	......	77.2
‡ 56	Girard Coal Co.		Pea.............		.95	36.85	40.24	21.96	3.56	77.09
† 57		St. Clair..		Vulcan.......	10.3	27.9	49.0	12.8	0.7	76.9
† 58		Fulton....		Clair........	3.2	32.9	43.1	20.8	......	76.0
† 59		Macoupin		Gillespie.....	12.6	30.6	45.3	11.5	1.5	75.9
‡ 60	Crerar Clinch Co.		Pana Duff......		4.88	35.59	40.11	19.42	3.58	75.7
† 61		Fulton....		Bryant.......	2.4	32.9	42.6	22.0	......	75.5
† 62		La Salle..		Streator......	9.9	33.2	42.2	14.6	......	75.4
† 63		Bureau....		Ladd........	12.0	32.3	42.5	13.2	......	74.8
† 64		Bureau....		Seatonville...	10.0	33.8	40.9	15.3	......	74.7
† 65		Will......	Wilmington Lump		15.5	32.8	39.9	11.8	......	72.7
‡ 66	Crerar Clinch & Co.		Centralia Duff..		1.50	36.10	36.00	26.40	4.04	72.10
†		Sangamon		Barclay......	10.8	27.3	44.8	17.1	......	72.1
† 67		Madison...		Collinsville...	9.3	29.9	40.8	16.1	3.9	70.7
† 68		Bureau....		Colchester....	11.6	25.0	44.8	18.6	......	69.8
‡ 69	Wenona Coal Co.		Duff............		1.72	33.58	34.74	29.96	4.37	68.32
† 70		Perry.....		St. John.....	13.6	24.5	43.5	15.4	1.8	68.0
† 71		Peoria....		Elmwood.....	1.4	27.7	35.4	35.5	......	63.1

‡ These analyses were made by the Illinois Steel Company at their Chicago plant and were doubtless taken from cars in the coal company's yards, hence the low percentages of moisture.

† These analyses were made by various persons and are published in Kent's Steam Boiler Economy and were doubtless taken from the mines.

and that in turn by six feet of limestone making an excellent roof. It is underlaid by a clay bed, about one foot thick, and this in turn by a bed of limestone about four feet thick.

The character of the roof and underclay and the thickness of the bed make this an ideal coal for long-wall mining.[2]

The Mendota coal bed, when of minable thickness, covers a larger area in Iowa than in Missouri. It is only its southern end that extends into Missouri. Its thickness varies from two and a half to a little more than three feet. It is overlaid by black fissile shale or "slate" about two feet in thickness, and this in turn by about four feet of limestone, thus furnishing a good roof, and by "brushing" down the shale, giving room for good roadways without the necessity of digging much beneath the level of the coal bed. There is no limestone bottom rock to this coal bed.

A coal bed which is thought to be the same as the Mendota coal extends over the greater part of the area of the Bevier coal. It is, however, too thin to be mined on a large scale under existing conditions. In Randolph and Macon counties it is about eighteen inches thick. It is mined for blacksmithing purposes at a few places and is said to be of extra quality.

The *Tebo* coal bed is confined chiefly to Henry county. Its geological relation to the Lexington coal bed is not known. Its average thickness is about two feet and a half. It is overlaid, like the Lexington coal, by two to three feet of shale with a two foot limestone bed overlying the shale. It is underlaid by a few inches of clay and then sandy shales and sandstones extend down to the base of the coal measure series.

The Tebo coal is hard and compact, but it contains rather abundant lenticular masses of pyritiferous shale which must be picked out before the coal is in good condition for the market.

The Jordan coal bed underlies a small area in the vicinity of Deepwater and Brownington, in Henry county. The bed is three and a half to four feet thick, and is underlaid and overlaid by shales. A large part of the area, where this coal bed is thickest, has been worked out.[3]

The Rich Hill coal bed lies in the southwestern part of the state. It is not fully demonstrated that the same coal bed extends over the whole of the area shaded for the Rich Hill coal on the map. It is,

(2) For the detailed geology and distribution of this coal bed in Ray and Lafayette counties, see the Geology of the Lexington Quadrangle, the Geology of the Richmond Quadrangle in Vol. XII. Reports of the Mo. Geol. Sur., and the Higginsville Sheet in Vol. IX.

(3) For detailed description of the Geology of Henry county, see the Reports on the Geology of the Clinton and Calhoun sheets in the Reports of the Missouri Geological Survey, Vol. XII.

however, known that coal of minable thickness underlies this area, and for that reason it was all shaded alike. The thickness of the bed varies from thirty to forty-eight inches, and locally is a little thicker. It is overlaid by shale and underlaid by shale in some places and by clay in others.[4]

In conclusion, thanks are due to the various mine operators for their kind co-operation, the Wabash; Missouri, Kansas and Texas; Burlington; Missouri Pacific; and Omaha, Kansas City and Eastern railroads for courtesies extended.

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(4) For more detailed descriptions of the coal bed and the mines in this part of the state, consult the Preliminary Report on Coal, Vol. I, Mo. Geol Survey, 1891.

MAP OF MISSOURI, SHOWING THE VARIOUS COAL BEDS.

ENGINEERING EXPERIMENT STATION BULLETINS.

Some Experiments in the Storage of Coal, by E. A. Fessenden and J. R. Wharton. (Published in 1908, previous to the establishment of the Experiment Station.)

Vol. 1, No. 1—*Acetylene for Lighting Country Homes*, by J. D. Bowles, March, 1910.

Vol. 1, No. 2—*Water Supply for Country Homes*, by K. A. McVey, June, 1910.

Vol. 1, No. 3—*Sanitation and Sewage Disposal for Country Homes*, by W. C. Davidson, September, 1910.

Vol. 2, No. 1—*Heating Value and Proximate Analyses of Missouri Coals*, by C. W. Marx and Paul Schweitzer. (Reprint of report published previous to establishment of Experiment Station), March, 1911.

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and two research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

TABLE OF CONTENTS

PART I.

INTRODUCTION

Unsatisfactory lubrication is a very common trouble and the selection of the very best lubricant, considering both quality and cost, is extremely difficult because of the almost complete absence of definite and precise information upon which to base an intelligent judgment.

It was the realization of this unsatisfactory condition, brought home by the difficulty of choosing between different lubricants for use in the University Power Plant that led the Engineering Experiment Station to attempt to develop apparatus and methods of testing that would yield definite information about the friction and the working characteristics of lubricants under service conditions.

This Bulletin is a preliminary report on the progress of this investigation.

PART II

CHARACTERISTICS OF FRICTION BETWEEN LUBRICATED SURFACES

The *general* characteristics of friction between *well* lubricated surfaces have been pretty well established and only a brief summary will be given here. In the first place it is necessary to point out that it is absolutely essential to have the surfaces thoroughly covered with lubricant. "There are no laws for partially lubricated surfaces."

Rubbing surfaces are lubricated in order to reduce *wear, temperature rise* and *energy losses* and the quality of the lubricant should be judged by the extent to which it reduces these effects. As reduction of energy losses usually results also in the reduction of wear and temperature rise the best lubricant would be taken to be the one giving the least energy loss *under service conditions* provided it did not develop some undesirable characteristic such as acidity or drying out rapidly to a gum, etc., when in use.

There are two radically different classes of service to be considered, namely, lubrication of bearings and the lubrication of engine cylinders.

The conditions in bearings are simpler and easier to meet. The temperatures are usually moderate and the direction of motion, the speed and the pressure constant.

For these reasons a number of machines have been built to measure the friction in bearings. [1] Professor Thurston's apparatus in which a split bearing is clamped on the shaft by spring pressure, thus giving

[1] Thurston. Friction and Lost Work. John Wiley & Sons.

an oil film thickness that depends on the constants of the oil as in railroad car bearings and Professor Stribeck's [2] in which a solid-shell ring-oiled bearing having an average oil film thickness that is constant (being determined by the difference in diameter of journal and bearing) a type very generally employed for machines, are particularly deserving of mention.

In engine cylinders the temperatures are high and subject to a wide cyclic variation, the lubricant is also subject to the high and varying pressure of the steam or gas as well as the pressure between the packing rings and cylinder walls; the motion is reciprocating and it is difficult to get the lubricant to the rubbing surfaces and to keep it from being blown on out with the exhaust. In steam cylinders the surfaces are covered with water.

Apparently only one apparatus has ever been built to measure directly the energy loss due to friction in steam cylinders. This apparatus was constructed about the year 1888 by Professor Denton at the Stevens Institute of Technology for the "Lubrication Committee of the Standard Oil Co." It is described in the Transactions of the American Society of Mechanical Engineers, Volume X, page 392, for the year 1889. The measurement in this case was made by having a piston ring free to move in a wide piston slot and fastening the piston ring to spring controlled levers. These levers were all attached to a rod lying in the axis of the cylinder within a hollow piston rod. When the piston moved, friction would make the rings drag and so move the central rod with regard to the piston rod.

Outside the cylinder a registering pencil made a diagram and the distance between the lines on the forward and return stroke was taken as a measure of the drag and friction of the piston ring. The records made in this way consisted of lines about 3-32 inch apart for a well lubricated cylinder with a piston ring pressure of about 70 pounds per square inch. The piston rings in large steam cylinders are usually made to exert a pressure of two or three pounds per square inch and even in the smallest cylinders the pressure is probably never more than fourteen pounds per square inch. The objections that might be urged against this apparatus are: that the value obtained for the friction coefficient depended upon the accurate measurement of the very small distance between two pencil lines; that the piston ring pressure that had to be employed to get even this record was many times the usual piston ring pressures; that the measurement gave the piston ring coefficient alone and there was no difference of steam pressure on the two sides of the ring. Moreover, the construction of the apparatus required a careful elimination of the inertia effects of the rod levers and piston ring by making the center

[2] Stribeck. Zeitschrift des Vereines Deutsche Ingenieure V. 45 p 122.

of gravity correspond exactly with the fulcrum of the radial lever connecting the central rod to the piston ring.

Notwithstanding these objections good work was done with the apparatus and great credit is due Professor Denton for its development.

When smooth surfaces are well lubricated the friction is reduced to that between the particles of the lubricant and depends upon the properties of the lubricant and not upon the material of the surfaces. Some of the lubricant sticks to the moving surface and moves with it; a similar film fastens itself to the other surface and the friction that results is due to the relative motion between the different layers of the lubricant, that is, the friction is determined by the internal resistance of the particles of lubricant to flow. This property of resistance to flow or the internal friction is called "viscosity." It is usually measured by the time required for a given volume to flow through a given sized opening under a given force. A unit of viscosity would be based upon the force required to move one of two parallel surfaces of unit size and distance apart at unit velocity with regard to the other.

The power loss due to friction would then increase with increase of viscosity, of rubbing speed and extent of surfaces, and is independent of the pressure between the surfaces until the pressure becomes high enough to squeeze the lubricant out. The greater the distance between the two surfaces the less will be the relative velocity of the different layers of the lubricant, and consequently the greater the distance between the two surfaces the less the friction will be provided that the lubricant completely fills the space between the surfaces.

In most cases the lubricant is carried from the point where it is supplied and spread over the rubbing surfaces by its tendency to stick to the moving surfaces and so be carried along with them. This tendency to stick and so get where it is needed seems to vary with the viscosity, and to this property the term "body" is applied altho no precise definition or measurement of this property has ever been made.

Lubrication is imperfect and friction high so long as the speed is too low to carry plenty of lubricant to the rubbing surfaces. To keep t e surfaces lubricated we must have a lubricant with a higher viscosity (or "body") the lower the speed and the greater the pressure between the surfaces, but so long as the viscosity or body of the lubri, cant is sufficient to keep it between the surfaces the lower the viscosity at the working temperature the better.

The viscosity decreases rapidly with rise of temperature so that the viscosity and friction tests must be made at the working temperature and the temperature must be measured with great care and accuracy.

The proper test for a lubricant is not then merely a viscosity measurement but a test for the friction under service conditions of temperature, speed, pressure and clearance.

When tested in this way it will be found that the lubricant that gives the best results is one with a higher absolute viscosity, the higher the temperature and the pressure and the lower the speed. Moreover by a proper choice of lubricant the friction coefficient may be brought to a minimum value and this minimum value is *practically the same* for all lubricants. In other words, for every lubricant (free from foreign and harmful ingredients) there is a set of working conditions under which it will give this minimum friction coefficient. This minimum friction coefficient lies between the values of ½ of one per cent and one per cent.

The apparatus for testing lubricants must therefore permit of the reproduction of any set of service conditions and, more important still, must make it possible to keep these conditions absolutely constant during the test or comparison.

These conditions are:

Adequate supply of lubricant.
Definite and constant values for the rubbing speed.
Definite and constant pressure.
Definite and constant temperature.
Definite and constant thickness of lubricating film (or clearance between the rubbing surface.

PART III

DESCRIPTION OF APPARATUS.

a. Apparatus for Testing Bearing Friction and Lubrication.

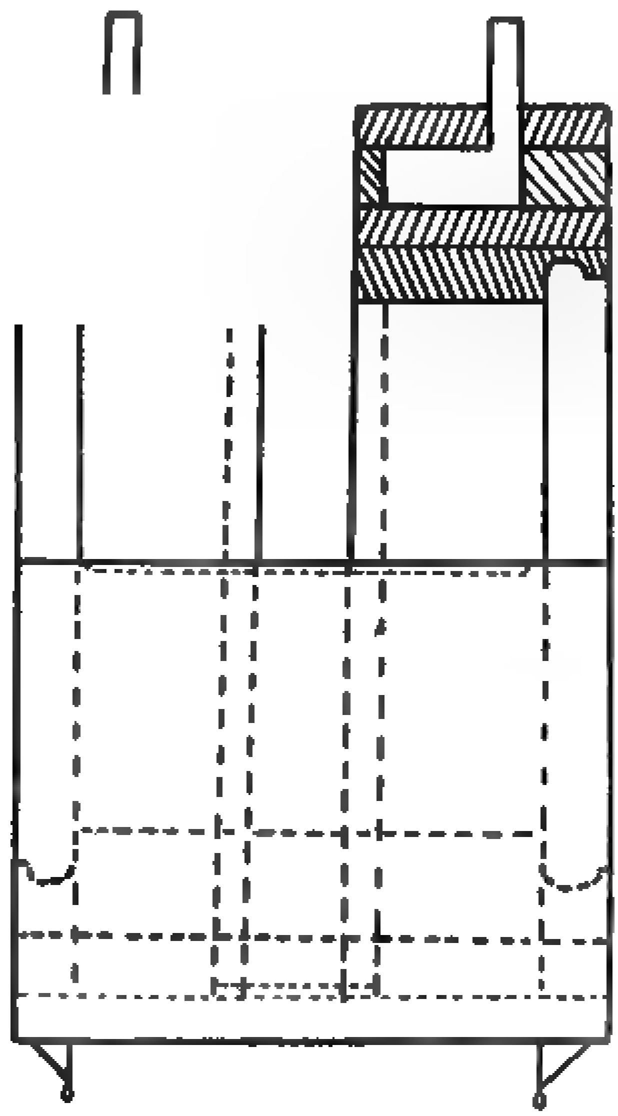
The accompanying photograph and sketch give an idea of the gen eral appearance of the apparatus. The principle adopted was that of measuring electrically the input to a motor driving a shaft that is supported by a single bearing and carries discs to produce the desired pressure on the bearing. The motor losses may be subtracted and so the net power used by the friction of the test bearing obtained. The speed is controlled by the voltage applied to the motor. The temperature is controlled by a water jacket and measured by a thermometer in a pocket close to the bearing surface. The pressure between the shaft and the bearing is determined by the number of discs put on the shaft. The clearance or play of the shaft in the bearing is determined by measuring the diameter of the shaft and the bore of the bearing.

The bearing in this apparatus is 2 ¼ inches in diameter and two inches long. The oil is carried from the reservoir by the usual type

of oil ring or rings to the top of the bearing and the amount of oil supplied measured by timing the drops from little drain pipes leading off from channels at each end of the bearing. The motor can be run at any speed up to 1200 revolutions per minute corresponding to rubbing velocities up to 708 feet per minute (215.8 cm. per second.)

b. Apparatus for Testing Steam Cylinder Friction and Lubrication.

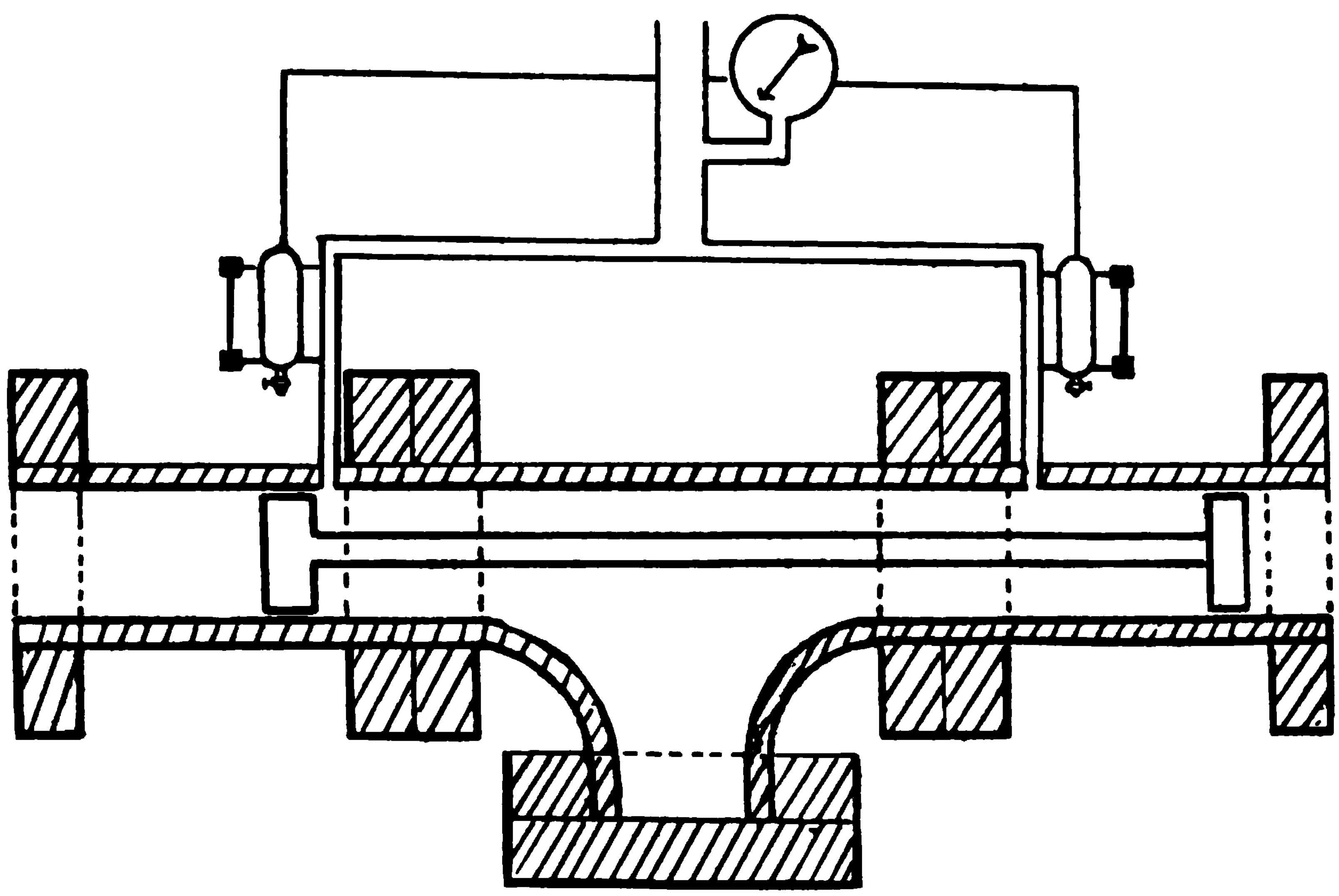
The method of measurement adopted here was, as in the previous case, to measure electrically the input to a motor and to subtract the motor losses. In this case the motor was provided with a crank disc



TEST BEARING

and connecting rod driving two pistons fastened on the opposite ends of a piston rod with a steam space and a pocket for collecting condensation between the two pistons. The construction is shown in the accompanying sketch and photograph, the latter showing also the gas heated, coiled tube boiler and the water tank, as well as the two

Detroit one pint lubricators connected to steam pipes entering the cylinder near the ends, just inside of the inner positions of the pistons. The use of two pistons of the same size with a steam space between them prevents the steam from doing any work itself or having work done on it. Each end of the connecting rod is fitted with Hess Bright ball bearings so that its friction is negligible compared with that of the pistons. Thermometers in pockets are provided nearly opposite the mid stroke positions and within 1-16 inch of the inner



TEST CYLINDER

wall of the cylinder and give an indication of the temperature of the rubbing surfaces. An Ashcroft standard test gage is used for measuring the steam pressure

The cylinder bore is 3 inches (7.62 cm) and the stroke was 3 inches (7.62 cm) when the apparatus was first set up, being changed later to 5 inches (12.70 cm.) There are three, standard type, cast iron, piston rings on each piston. Each ring has a face width of .2175 inches (.553 cm.) These rings gave a pressure of about 3.23 pounds per inch of circumference and 14.92 pounds per square inch (.577 kg. per cm. and 1.050 kg. per sq. cm.) after being worn to a fit.

As the cylinder ends are open only one face of the piston is subjected to steam pressure and temperature, the other face being subject to conditions corresponding to those of the exhaust of a non-condensing engine. The oil fed to the steam pipes entering the cylinder

near the position occupied by the pistons at the inner end of their strokes is carried to the rubbing surfaces by the steam as in the steam engine.

Both pieces of apparatus are in their development period and it is expected that improvements will be made and the range of conditions extended as additional experience is gained. Some of the changes and improvements already contemplated are:

An additional bearing for the bearing testing apparatus, split in order to make tests with a clearance distance that will be absolutely unaffected by wear.

A larger cylinder bore for the cylinder friction testing apparatus.

A set of spiral-spring-controlled piston rings allowing adjustment for different piston ring pressures.

PART IV

RESULTS OF TESTS

A test apparatus to be of any real value must first of all give reproducible results and the test figures quoted here are intended principally to show what may be expected in this respect.

The following values were obtained with the first apparatus set up for testing bearing friction. The bearing in this case was a standard motor bearing, solid babbitted shell 4 inches long, 1¼ inches bore, having two oil ring slots and four oil rings, *two rings in each slot*. The bearing had a projected area of 3.9 square inches, a load of 176 pounds and a pressure of 45.2 pounds per square inch.

Bearing Friction Test Results

Date	Bearing temp. degs. centigrade	Speed		Current in Amperes			Power Consumption of Bearing	Friction coefficient
		R.P.M	Feet per Minute	Total	Motor losses	Net	Watts	
8-18-1910	35.0	700	232.5	2.20	.57	1.63	22.85	.02475
8-22-1910	35.1	700	232.5	2.27	.57	1.70	23.93	.02594
8-23-1910	35.6	693	230.7	2.26	.57	1.69	23.40	.02564
8-24-1910	35.8	693	230.7	2.20	.57	1.63	22.50	.02470

One interesting and altogether unexpected peculiarity of bearing lubrication was discovered during the preliminary trial tests on this bearing, and later confirmed by tests on the 2¼ inch bearing.

This was that with the single oil ring in each slot *supplied by the manufacturer* the oil supply was insufficient and the friction high and variable, the range being from a well defined minimum to a value

twice as large. This difficulty was completely eliminated by the use of *two* rings in each slot, the two nearly but not quite filling the slot.

The cylinder friction apparatus test results quoted in the table below, as well as those plotted in the accompanying curve sheet were taken just after the apparatus had been set up and while the surfaces were still only partially worn smooth. They are given principally to illustrate the reproducibility of results.

Cylinder Friction Test Results; 3" Cylinder, 3" Stroke.

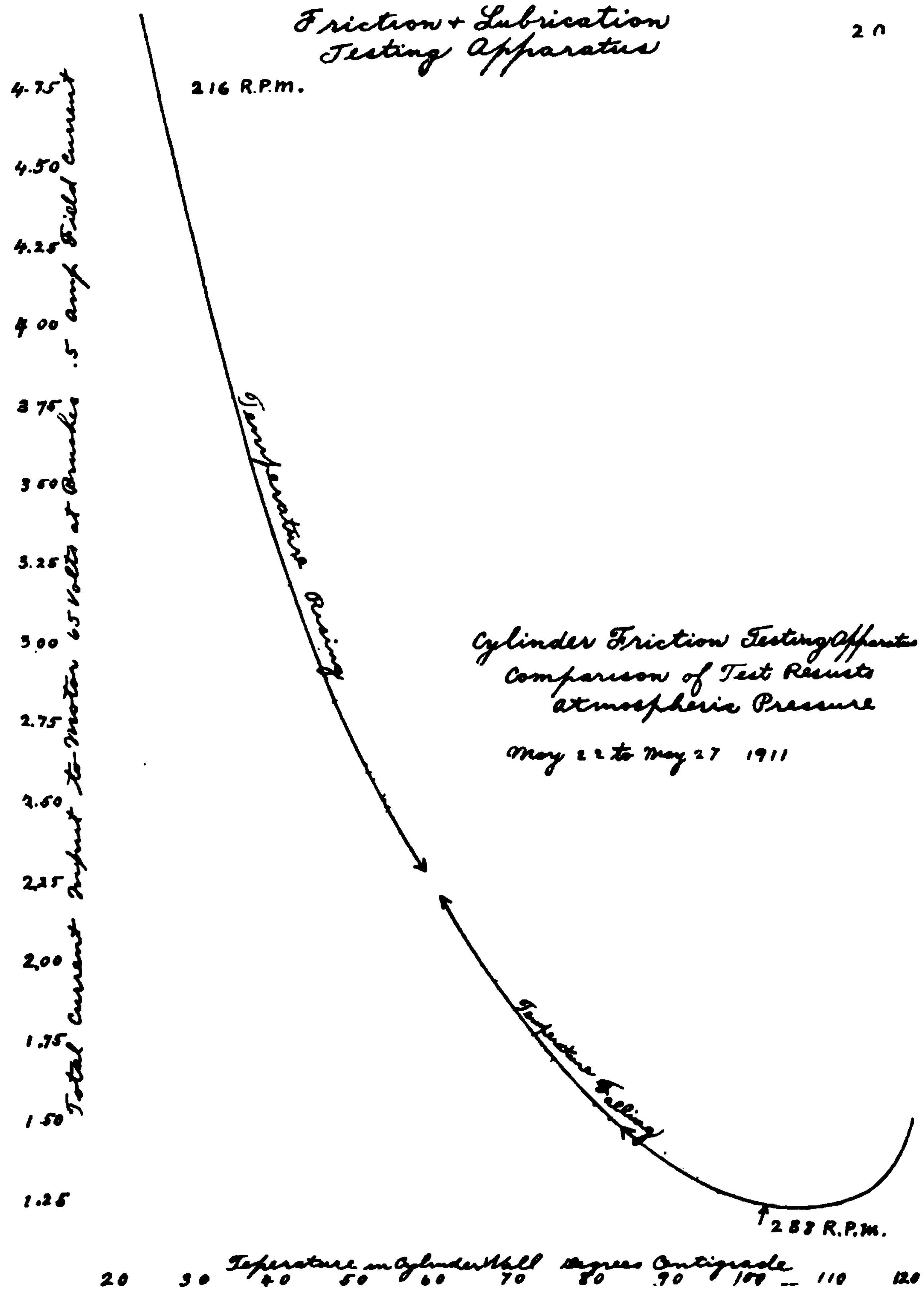
Date and Time	Gage pressure pounds per square inch	Temp incylinder wall degrees Centigrade	Oil Feed, Seconds per Drop	Speed		Current in Amperes			Friction coefficient
				R.P.M.	Feet per Minute	Total	Motor Loss	Net	
	Cylinder Filled With Steam at Atmosphere Pressure								
Apr. 3, '11 9:35 p. m.	0	94.4	67.3	277	217.5	1.23	.266	.964	.02728
11:14 p.m.	0	95.6	26.2	275	216.0	1.26	.266	.994	.02810
Apr, 4, '11 12:15 a.m.	0	94.0	72.7	274.5	215.5	1.26	.265	.995	.02815
Apr. 5, '11 9:10 a. m.	0	94.0	62.0	274.0	215.	1.27	.265	1.005	.0284
9:35 a. m.	0	94.	73.2	274	214.5	1.27	.265	1.005	.0284
	Cylinder Filled with Steam Under Pressure								
Apr. 3. '11 10:45 p.m.	19	119.3	24.4	253	198.8	1.72	.257	1.463	.0414
10:50 p.m.	21.5	120.6	24.4	255	200.5	1.68	.257	1.42	.0402
Apr. 5, '11 10:30 p.m.	20	120.5	45.0	249	195.4	1.80	.256	1.54	.0436

The increase of friction in the cylinder when the outlet is closed and the steam pressure raised has been confirmed by a number of subsequent tests. There are several influences at work.

1. The flow of steam carries the oil to the rubbing surfaces tending to reduce the friction.

2. The leakage of steam past the piston rings carries the oil away so that the friction tends to increase unless the oil supply is greatly increased.

3. The steam also leaks into the space back of the piston rings causing them to press against the cylinder wall more firmly and so tending to increase the friction.



4. The decreased viscosity at high temperatures allows the oil to be squeezed out, tending to increase the friction unless the speed be raised or the piston ring pressure lowered.

The effect of the first factor was detected by suddenly applying air pressure to the inner faces of the pistons. At once the friction decreased slightly as the air forced more oil along with it to the rubbing surfaces. This effect is, however, very small, the change in one case being from 2.08 amperes supplied to the motor with zero gage pressure to 2.02 amperes when the air pressure was suddenly raised to 20 pounds per square inch gage pressure. (Test April 20, 1911).

The effect of leaking steam in carrying away oil and increasing the friction is very marked. The current required to drive the machine decreasing from 3.77 amp. with an oil feed of 37.0 seconds per drop to 2.58 amp when the oil feed was increased to 9.4 seconds per drop. Furthur increase of oil feed did not decrease the friction, the current required for a rate of oil feed of 3.4 seconds per drop being 2.57 amp. (Test June 8, 1911.)

The effect of steam pressure in the piston ring slots was detected by arranging drains so that the backs of the piston rings could either be subjected to full steam pressure or to atmospheric pressure. With full pressure on the backs of the rings the friction with increasing steam pressure rose more rapidly than before while with the piston ring slots open to the atmosphere the friction actually decreased with increasing steam pressure. (Tests of May 26 and May 27, 1911.)

The effect of temperature in lowering the viscosity to a point where it may be squeezed out unless the speed is raised or the pressure between the rubbing surfaces lowered is a well known characteristic of oils. That this effect is a factor in the increased friction is shown by the part of the curve above 107° on the curve already shown, which was taken with constant atmospheric pressure. (Test of May 27, 1911.)

This was further checked by making runs with decreased piston ring pressure in which the temperature for minimum friction was much higher (about 137° C for half normal piston ring pressure. Test June 5. 1911) and by runs at a higher speed which also gave a high temperature for minimum friction (about 142° C, for a little over double speed. Test June 8, 1911.)

PART V

CONCLUSIONS

The tests so far made with the preliminary apparatus lead to the following conclusions:

1. A fair degree of reproducibility and a moderate amount of experimental error has already been obtained.
2. A single oil ring per slot in an oil ring bearing may not supply sufficient lubricant.
3. The friction in steam cylinders may under some conditions increase with increase of steam pressure.
4. The principal causes so far found for the increase of steam cylinder friction with increase of steam pressure are:
   a. Leakage past the piston rings carrying away lubricant and requiring an increased oil supply.
   b. Presence of steam pressure on the backs of the piston rings thru leakage.
   c. Decreased viscosity at high temperatures allowing the piston rings to squeeze the lubricant out.

It is a pleasure to acknowledge here the help given by members of the faculty of the University of Missouri and by the discussion at the annual convention of the Missouri, Gas Electric Light, Street Railway and Water Works Association.

It is expected that additional test results will be obtained and that they will be incorporated in a separate Bulletin.

PART VI

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THE UNIVERSITY OF MISSOURI BULLETIN

ENGINEERING EXPERIMENT STATION SERIES
VOLUME 2. NUMBER 3.

AN INVESTIGATION OF THE ROAD MAKING PROPERTIES OF MISSOURI STONE AND GRAVEL

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COLUMBIA, MISSOURI.
September, 1911

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July, 1, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and two research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

INTRODUCTION.

Realizing the popular interest that has been awakened for good roads in Missouri and elsewhere in recent years and that the majority of the permanent roads must have for their wearing surface suitable rock or gravel that can be obtained at a reasonable cost, The Engineering Experiment Station of the University of Missouri undertook the investigation of the road making properties of Missouri stone and gravel in the fall of 1910. In this investigation the Station has had the cooperation of Mr. Curtis Hill, State Highway Engineer, who has rendered very valuable assistance in securing the testing apparatus and in collecting the materials for testing.

On November 22, 1910, Messrs. L. P. Scott, G. C. Broadhead, and R. A. See, all graduates of the Civil Engineering Department of the University of Missouri, were sent out to collect samples of stone and gravel that might be used in road building. Each of these men was instructed to cover a certain part of the state, confer with the County Highway Engineers, other county officials and prominent men interested in good roads; and collect samples from as many quarries and gravel banks as possible in the time allotted for this work. The time allowed for making this collection was limited as this work had to be completed before Jan. 1, 1911; therefore a few counties which have abundant road material had to be omitted, other counties were not visited as it was known that they had very little or no road material of this character.

The wearing surface of a macadam or gravel road, often called the road metal, must possess certain physical properties in order to be a good road material. These properties are hardness and toughness to resist the wear of the traffic, and cementing properties to bind the stones together and produce a smooth hard surface. These qualities are often found in the same stone but sometimes a combination of two materials are required to produce the best results, one for hardness and toughness and the other for a binding material. The laboratory tests have been arranged to bring out the comparative values of these desirable physical properties. The testing machines and the methods of testing are the same as those used by the Office of Public Roads of the U. S. Department of Agriculture; so the result can be compared directly with those published by the Office of Public Roads at Washington D. C. A few of these tests have been made by senior students in Civil Engineering under the supervision of the director of the road laboratory, but nearly all of them have been made by Mr. R. Warren Roberts, personally, in connection with his thesis for the degree of Civil Engineer.

Most highway engineers and road builders will agree that the

best test of a road material is its action under the traffic it is required to carry, but this test is an expensive one and requires a year or more to carry it out; therefore the purpose of these laboratory tests is to enable the highway engineer to ascertain in advance if a stone is satisfactory for road building purposes, or if there are several kinds of material available, which is the best or what combination of available materials is likely to give the best results.

It is the hope of the authors of this bulletin that the results of these tests will prove to be a valuable aid to the highway engineers of the state in selecting the material for building the permanent roads of the state.

The methods used in making the tests will be described in detail and then the counties from which samples have been obtained will be taken up in alphabetical order. Each sample (numbered in the order in which the tests were made) will be described, its location definitely given and the results given from the tests for the French Coefficient of wear, for cementing value, for hardness, and for the resistance to impact or toughness, as these four tests indicate the physical properties which determine the value of a material for road building purposes.

The results of these tests, together with the specific gravity, weight per cubic foot, and water absorbed per cubic foot will be shown in tabular form so that comparisons can be readily made.

A part of each sample has been placed in a glass jar, properly labeled, and kept in the laboratory as an exhibit.

It was at first contemplated to publish a map of the state in this bulletin, on which the location of each sample tested would be shown by its number, but it was decided later to omit this map as it would be too bulky if made large enough to be satisfactory. If any one wishes such a map for comprehensive study of these results, it can easily be prepared by taking any good map of the state, such as the State Railroad Commissioners' Map, and placing the number of each sample in its proper place from the description of the locality from which it was obtained.

DESCRIPTION OF METHODS AND APPARATUS FOR TESTING ROAD MATERIALS.

ABRASION MACHINE.
(Deval Type.)

This machine (Fig. 1) consists essentially of the pully "A", driving the shaft " B B," upon which are mounted the two cast iron cylinders "C C" in such a way that the axis of the cylinders are inclined at an angle of 30 degrees with the axis of rotation. The cylinders are 20 cm. in diameter and 34 cm. in depth inside. The shaft is set in two bearings "D D" and carries at "E" a revolution counter. The method of fastening the cylinders to the turning frame is shown at "F."

ABRASION TEST.

Five killograms (11 lbs.) of rock, broken in pieces as nearly uniform in size as possible and as nearly 50 pieces as possible constitute a test sample. The pieces must pass a 2½ inch ring and be retained on a 1 inch ring. The total weight of rock in a test is within 10 grams of 5 killograms. All test pieces are washed free from ali detritus and thoroughly dried in an oven before weighing. Three hours at a temperature of 150 degrees centigrade is ample length of time for thorough drying.

The test sample is now weighed and placed in the machine. Ten thousand revolutions, at the rate of between 30 and 33 revolutions to the minute, constitute a test. After the test the sample is washed free from all detritus and dried again. Only the percentage of material worn off which will pass through a 0.16 cm (1-16 inch) mesh sieve is considered in determining the amount of wear. The amount of wear is expressed either in the per cent of the 5 killograms used in the test, or the French coefficient, which is in more general use, is given. That is, the coefficient of wear equals $20 \times \frac{20}{w}$ equals $\frac{400}{w}$ equals $\frac{40}{\text{per cent of wear.}}$ "W" being the weight in grams of the detritus under 0.16 cm. ($\frac{1}{16}$ inch) in size per killogram of rock used.

In interpreting results of this test a coefficient of wear below 8 is considered low, between 8 and 13 medium, between 13 and 20 high, and over 20 very high.

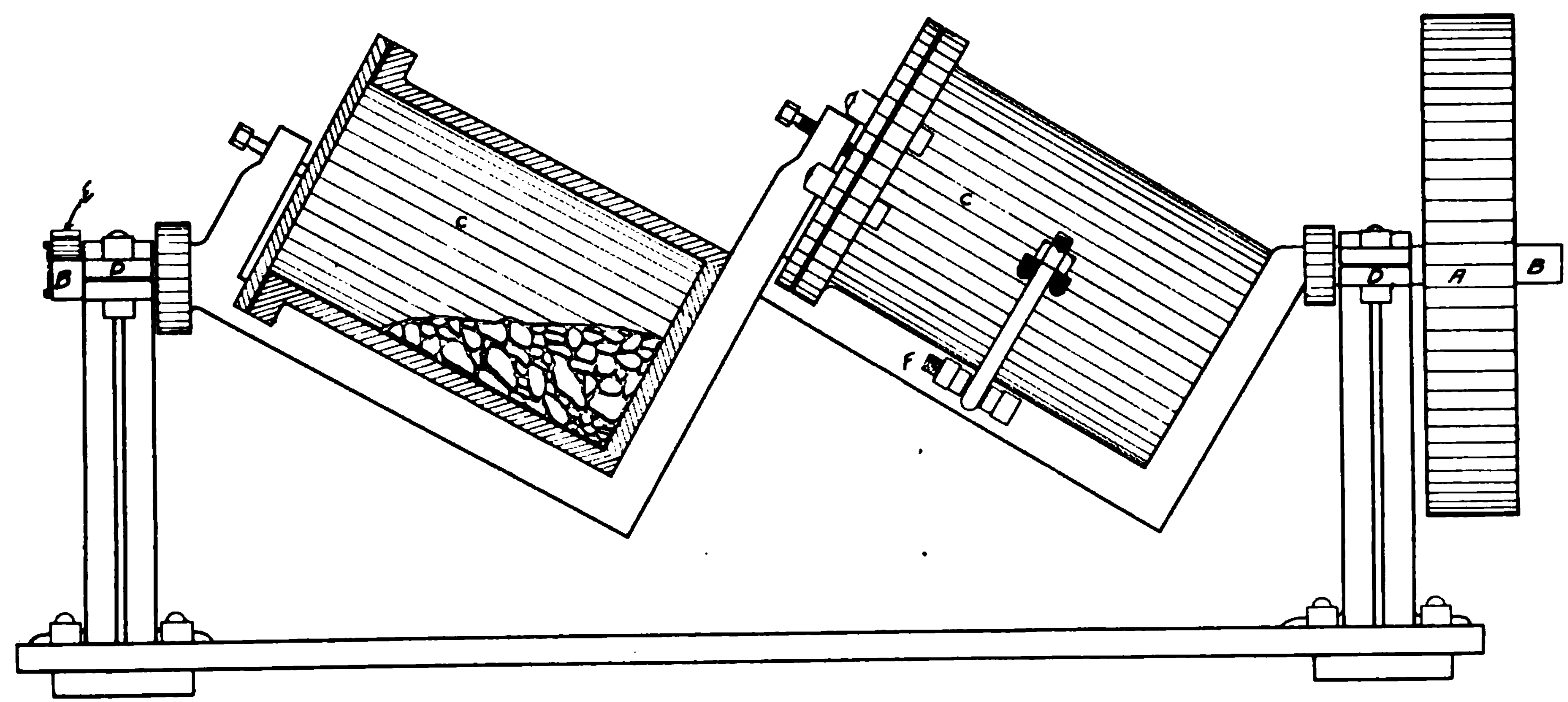


Fig 1

Abrasion Machine. (Deval Type.)

(Fig. 13.)

Samples of Granite, Limestone, and Sandstone Before and After the Abrasion Test.

No. 1 Granite retained on a 1 in. screen.
No. 1a Granite retained on a 1-16 in. screen.
No. 1b Granite passing a 1-16 in. screen.
No. 2 Limestone.
No. 3 Sandstone.

CEMENTATION TEST.

One half killogram of the rock to be tested is broken sufficiently small to pass a one half inch mesh. This material is placed in a ball mill (Fig. 3) together with about 90 cubic centimeters of water sufficient to produce a stiff paste after grinding. At the end of 5,000 revolutions, the material is taken from the mill and about 28 grams of the dough is placed in a cylindrical metal die 25 mm. in diameter. A closely fitting plug (see fig. 4) supported by guide rods is inserted over the material which is then subjected to a pressure of 132 killograms per square centimeter. The die is placed on an iron platform supported by a piston rod which is connected directly with an hydraulic piston below. Water under pressure is admitted to the hydraulic cylinder through a small orifice in the pipe. As the piston rises, the platform and die are carried up with it, the plug of the latter coming in contact with a yoke attached to a properly weighed lever arm. The height of the briquet is measured and if it is not exactly 25 mm. (.98 inch) in height, the requisite amount of material is added or subtracted to make the next briquet the required height. Five briquets are made from each test sample and allowed to dry 20 hours in the air and 4 hours in a water bath at 100 C. After cooling 20 minutes in a dessicator, they are tested by impact in a machine especially designed for that purpose.

This machine (fig. 6) consists of a 1 kilogram hammer which falls on a flat end plunger of ½ kilogram weight, which is pressed upon the briquet by two light spiral springs surrounding the guide rods. The standard fall of the hammer is 1 centimeter and this blow is repeated until the bond of cementation of the material is destroyed. The number of blows required to destroy the bond of cementation as described above is noted and an average obtained from the five briquets as a cementing value.

In interpreting results of this test, values below 10 are called low; from 10 to 25, fair; from 25 to 75, good; from 75 to 100, very good; and above 100, excellent.

THE PAGE IMPACT MACHINE FOR TESTING CEMENTING VALUE OF ROCKS.

The hammer "G" is raised by means of the grip "F". The rise of the grip is such as to give an effective drop of 1 cm. to the hammer. The reaction of the briquette after each blow of the hammer produces a vertical movement in the end of the lever "L". This motion is recorded on a sheet of silicated paper wrapped around the recording drum "M" by means of a brass point at the end of the lever "L". The number of blows necessary to destroy the bond of the briquette is taken to be the cementing value of the material.

(Fig. 6.)

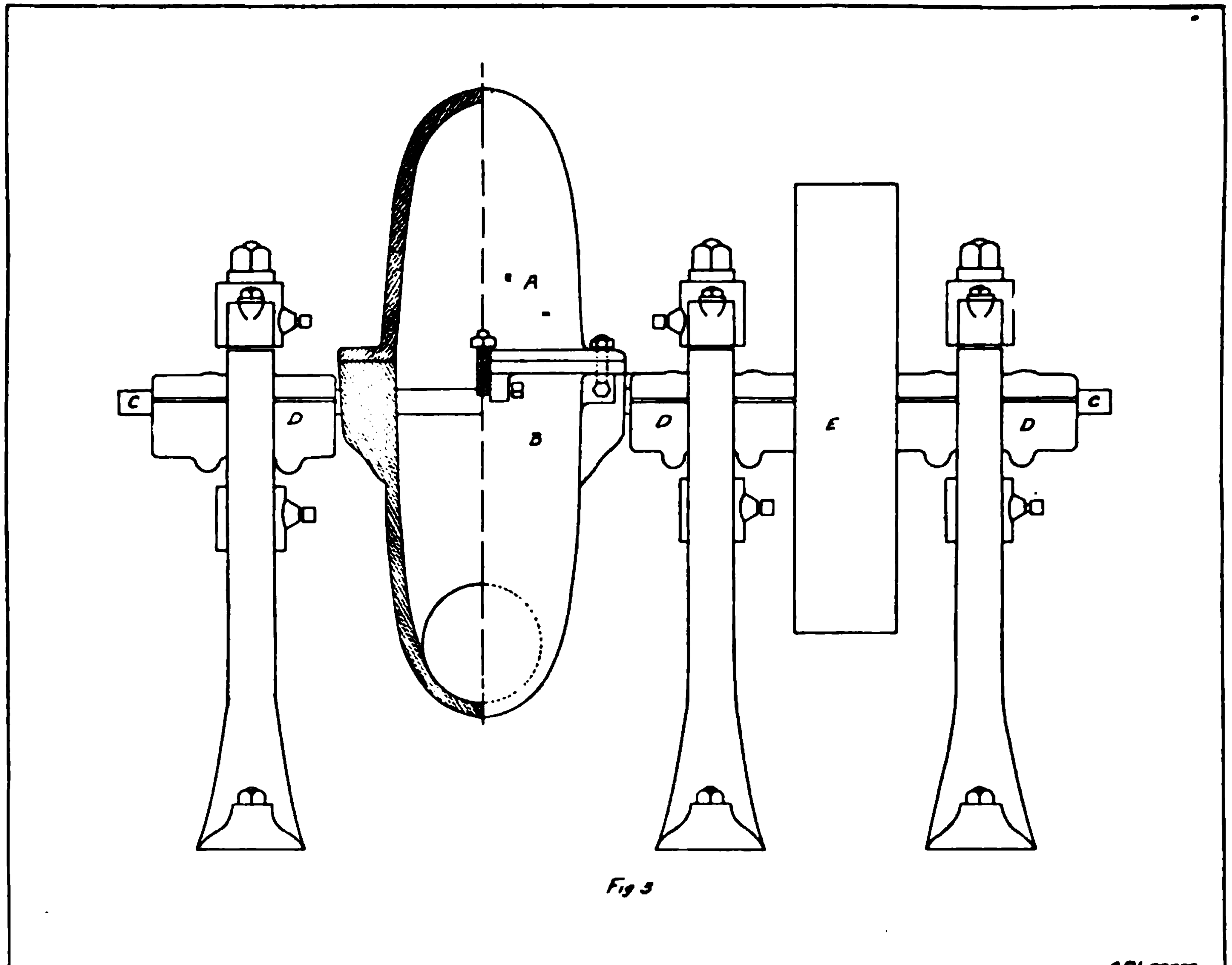
The Page Impact Machine for Testing Cementing Value of Rocks.

BALL MILL.

For Grinding Rock Samples.

The circular cast mill "A B", consisting of the two unequal segments "A" and "B", revolves in a vertical plane about the shaft "C C", which bears in the pillow blocks "D D", and is driven from the pulley "E".

Five hundred grams of coarsely crushed rock sample and about 90 cubic centimeters of water are placed, together with the steel shot 13 cm. in diameter, in the mill; the segments bolted together at F and the sample ground for 2½ hours in the mill revolving at the rate of 2,000 revolutions per hour. The grinding action of the steel shot reduces the rock sample to a stiff dough, in which condition it is ready to be moulded into biquets.

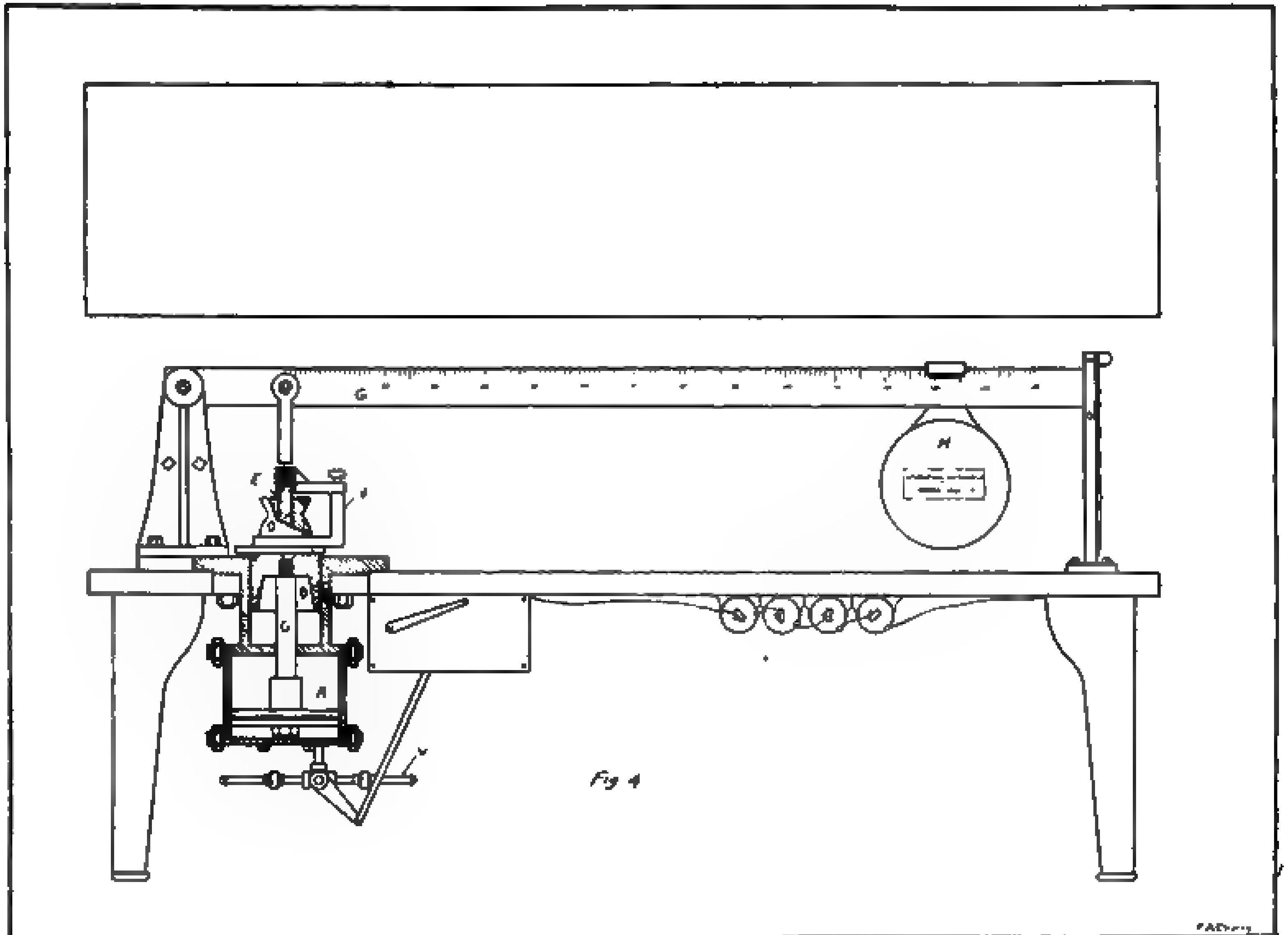


Ball Mill (For grinding rock samples.)

BRIQUETTE MACHINE.

For Molding Rock Dust Specimens

The hydraulic cylinder "A" (Fig. 4) supports an iron platform "B" through the piston-rod "C", the cylindrical metal die "D", provided with a closely fitting plug "E" supported by the guide rod "K" and containing the material to be compressed, is placed upon the platform and water admitted to the cylinder through the supply pipe "L". As the piston rises, the platform and die are carried up with it, the plug of the latter coming in contact with a properly weighted lever arm "G". The weight "H" is adjusted on the lever arm, so as to give a maximum pressure of 132 kilograms per square centimeter on the compressed material, which pressure is applied only for an instant. The electrical attachment shown is not in use at present, as it has been found more satisfactory to operate the water by hand.



Briquette Machine. For molding rock dust samples.

CORE DRILL.

For Preparing Rock Cores.

This machine (Fig. 7) consists essentially of a drill press in which may be placed a core drill.

The steel core tube "A" carries at its lower end the brass ring "B" containing four black diamond points, spaced as shown, to cut a rock core (see Fig. 8) 25 mm. (.98 inch) in diameter, the core tube is connected at the upper end with the brass casing "C" through which passes the lower part of the sank "D".

The water supply tube "F" is connected directly to the stationary brass ring "G" which has a semi-circular section cut on its inner side to fit a similar section in the casing "C" forming a circular hollow tube, one-half of which is stationary and the other half movable with the drill. Four small holes "I" forming the vertical tube "J", connect the ring with the inside of the core tube "A", the whole forming an arrangement for carrying water from supply tube "F" to the inside of the revolving drill, thereby flushing out the cuttings.

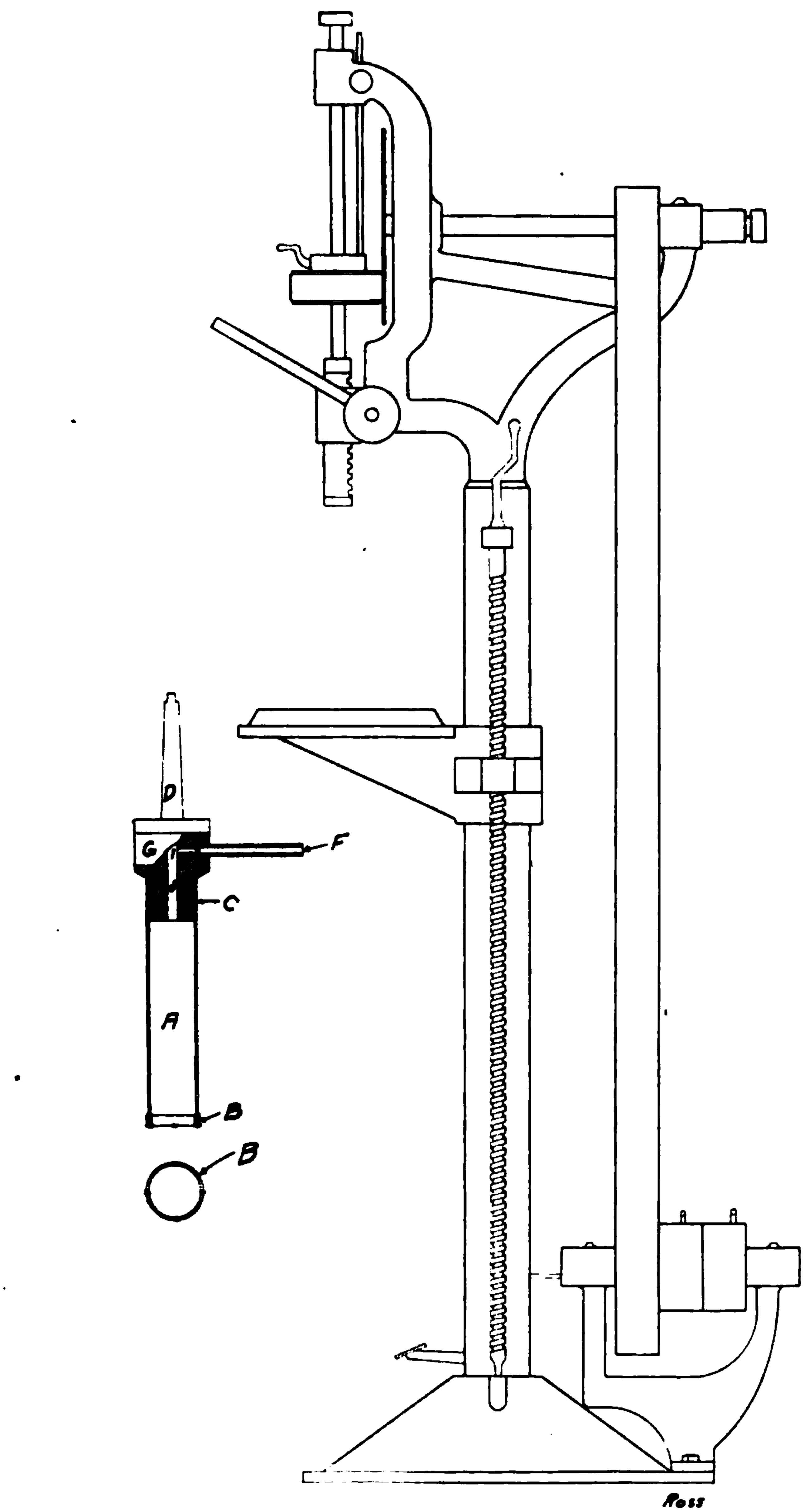


Fig 7
Core Drill. (For preparing rock cores)

(Fig. 8)

Samples of Rock From Which Cores Were Cut.

No 1. Red Granite	No 3. White Sandstone	No. 5. Red Granite	No. 7. Marble
No. 2 Dolomite	No. 4. White Limestone	No. 6. Mineral Bearing Limestone	

(Fig. 10)

Cutting the Cores for the Hardness and Toughness Tests.

HARDNESS MACHINE.

Dorry Type

The circular cast steel disk "A" revolves in a horizontal plane about the vertical shaft "B" which is driven from the pulley "C" by means of the bevel gear "D". The cylindrical rock core 25 mm. in diameter is clamped in the clip "F" and held in position over the revolving disk, so that the lower end of the test specimen rests against the disk with a pressure of 1250 grams. Sand, between 30 and 40 mesh, obtained by screening crushed quartzite, is fed continuously upon the disk through the funnel "G". Water is also fed upon the disk through the funnel "H".

This machine is equipped for making six tests at a time, the specimens being held on opposite sides of the grinding disk at a distance of 26 cm. from the center.

(Fig. 11)

Hardness Machine.

(Dorry Type)

TEST FOR HARDNESS.

A cylindrical core 25 mm. in diameter and 25 mm. high is cut from a specimen of the rock with a diamond core drill (see Fig. 7) and the piece is held perpendicularly against a revolving cast iron disk (see Fig. 11) under a constant pressure of 1250 grams, while standard quartz sand, between 30 and 40 mesh, is fed on the disc to act as the abrasive agent. At the end of 1,000 revolutions the loss in weight is determined and the test repeated with the specimen reversed.

Hardness........H equals 20—1-3 w.

Where W equals loss in grams per 1,000 revolutions. In interpreting results of this test all rocks below 14 are called soft; from 14 to 17, medium; above 17, hard.

TOUGHNESS, OR RESISTANCE TO IMPACT.

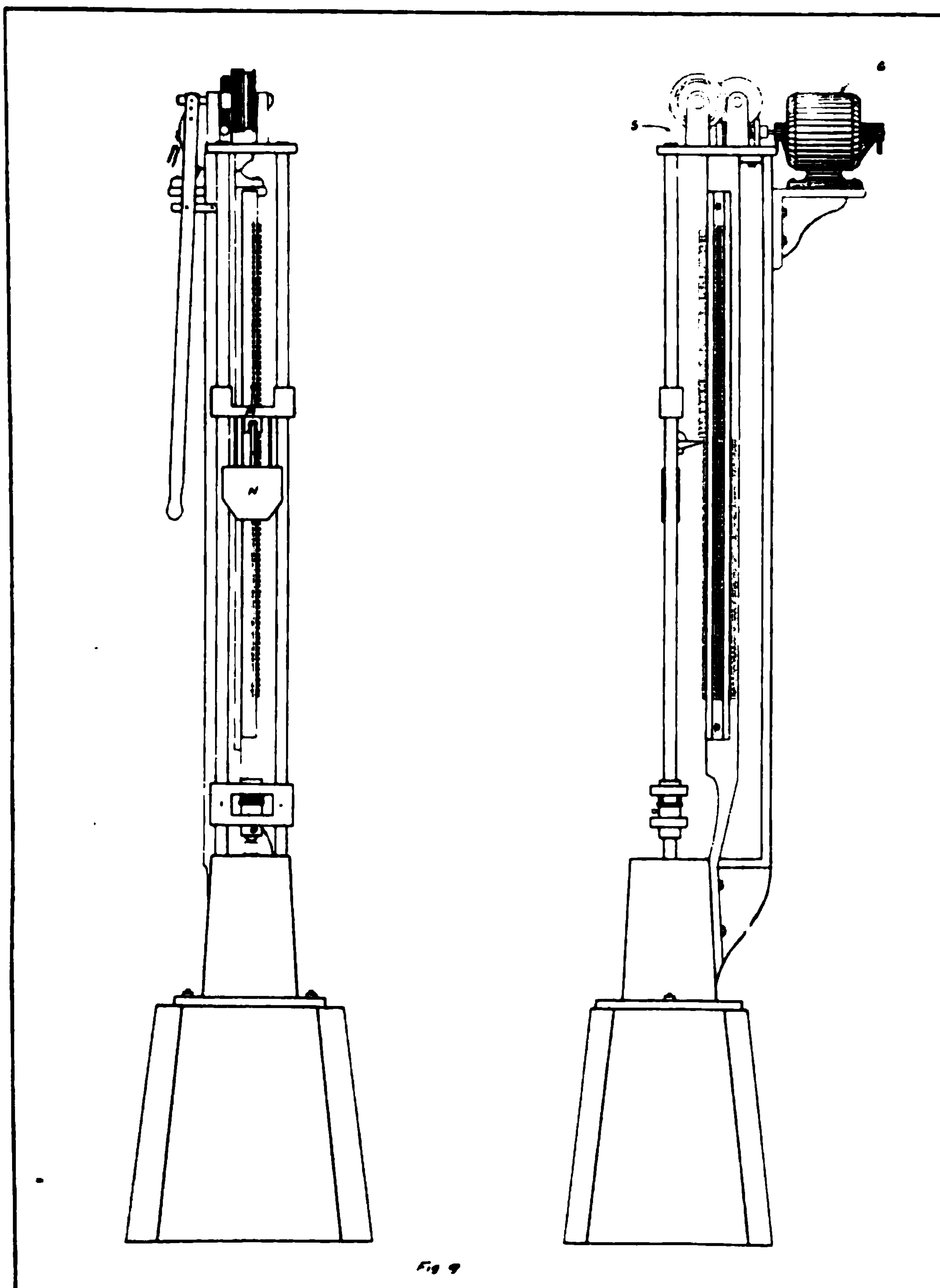
This test is made on 25 mm. x 25 mm. (0.98 in) rock cylinders with an impact machine (see Fig. 9) especially designed for the purpose, instead of a flat end plunger resting on the test piece as in the cementation test, a plunger with the lower bearing surface of spherical shape, having a radius of 1 cm. (0.4 inch) is used. It can be seen that the blow as delivered through a spherical end plunger approximates as nearly as practicable the blows of traffic. The test piece is adjusted so that the center of its upper surface is tangent to the spherical end of the plunger, and the plunger is pressed firmly upon the test piece by two spiral springs which surround the plunger guide rods. The hammer weighs 2 kg. and is raised by a small cable, and released by a trigger coming in contact with projecting pins spaced 1 cm. on centers. The test consists of a 1 cm. fall of the hammer for the first blow, and an increased fall of 1 cm. for each succeeding blow until failure of the test piece occurs. The number of blows required to cause failure is used to represent the toughness.

In interpreting results of this test, those rocks which run below 13 are called low; from 13 to 19, medium; and above 19, high.

IMPACT MACHINE FOR TESTING TOUGHNESS OF ROCK.

The motor "C" drives the cable "S" by means of a worm gear, this raises the crosshead "M" which carries the 2 Kg. hammer "N".

The trigger on the crosshead "M" strikes projecting pins on the frame, which are spaced one cm. apart. This releases the hammer "N" which falls upon the spherical plunger "O" and the blow is transmitted to the test specimen which rests on the anvil "W".



Impact Machine For Testing Toughness of Rock.

ABSORPTION TEST.

A piece of the abraded stone weighing from 50 to 70 grams was dried in an oven for 5 hours then weighed and placed in water for 96 hours, it was then wiped off on the outside and weighed again and the amount of water absorbed per cubic foot was computed.

RESULTS OF INVESTIGATION, BY COUNTIES.

ADAIR COUNTY.

Only one sample was received from this county, No. 50, blue limestone with a very close dense texture, sharp fracture, and containing a few large crystals of calcite. This sample comes from a quarry on the bank of Big Creek near Kirksville, the crushed stone being used on the macadam streets of Kirksville. The tests show a low coefficient of wear, 6.3; and a good cementing value, 33.4; hardness of 12.9; and a low resistance to impact, 7.0.

ANDREW COUNTY.

Sample 18, gray limestone with fine grain, having a rough fracture, and containing streaks of calcite; taken from Rheinhart's quarry, on the property of Evans Paul, three miles south of Savannah on the C. G. W. R. R. The ledge is about 18 feet thick and the crushed stone has been used in Andrew and Buchanan counties for road metal. Tests show a low coefficient of wear, 5.8; a fair cementing quality, 19.0; hardness of 9.4; and a low resistance to impact, 6.0.

Sample 19, blue limestone of medium close texture, containing streaks of calcite; takes from the quarry of Newton, Whitford and Knight on the farm of E. J. Blakeslee, four and one half miles north of Savannah on the C. G. W. R. R. The ledge is about 30 feet thick and has a large face developed. Crushed stone is shipped to St. Joseph and elsewhere. Tests show a low coefficient of wear, 6.2; good cementing quality, 39.6; hardness of 9.4; and low resistance to impact, 10.0.

Sample 20, brown limestone, known locally as "Butcher Stone", it has a coarse open texture and contains much clay, sand and fossils; taken from the same quarry as sample 19. The ledge is above the blue limestone and is about 4 feet thick. Tests show a very low coefficient of wear, 3.7; a fair cementing value, 23.2; hardness of 5.6, which is very soft; and a very low resistance to impact, 6.0. A poor road metal.

AUDRAIN COUNTY.

The only material received from this County was a sample of blue limestone, No. 242, taken from Telford foundation on North Jefferson street in Mexico after twenty years of service. It came

from a quarry in the northwest part of the City of Mexico. Tests show a medium coefficient of wear, 8.2; and an excellent cementing value, 112.0. Hardness and toughness tests were not made.

BARTON COUNTY.

Sample 109, bituminous limestone, very dark color, crystalline structure, coarse texture, very rough fracture, containing large crystals of calcite and numerous fossils; taken from the bank of Dry Fork of Spring River, five miles east of Lamar. Tests show a low coefficient of wear, 5.0; good cementing value, 41.0; very soft, 1.99; and a low resistance to impact, 6.0.

Sample 110, flint rock (known locally as "nigger heads"), it shows all gradations from flint to chalk, porous and pitted near the outside, colored red by oxide of iron, and contains numerous fossils. This sample was taken from the roadside three miles out from Lamar. It is found in scattering deposits in the southeast corner of the county and has been used to some extent on the streets of Lamar with only fair success. Tests show a medium coefficient of wear, 10.3; good cementing value, 34.4; very hard, 19.1; and a low resistance to impact, 11.0.

Creek gravel is found in the southeastern part of the county, but no sample of this was obtained.

BATES COUNTY.

Limestone is the only road material found in this county, it occurs in abundance in the north half of the county and there are scattering outcrops in the south part, the southern part being largely sandstone and shale.

Sample 103, gray argillaceous limestone with fine grained dense texture, containing a little sand; from William Herring's quarry at the east edge of Butler. Tests show a medium coefficient of wear 10.0; good cementing value, 26.0; hardness of 11.7; and a very low resistance to impact, 3.0.

Sample 104, gray limestone, coarse grained crystalline structure, contains numerous fossils and a small percent of clay, and has a ragged fracture. Obtained from a quarry on Chas. Argenbright's farm on the north side of Butler. The tests show a low coefficient of wear, 6.1; good cementing value, 50.4; hardness of 13.4; and a low resistance to impact, 11.0.

BENTON COUNTY.

Sample 100, a coarse grained crystalline limestone with grayish brown color; it contains many fossils and has a smooth sharp fracture and close texture. This sample comes from Thompson's quarry about one mile up the Osage River from Warsaw. This rock does not occur in very thick strata but grades off into "cotton rock"; it is

found only along the Osage River. The tests show a low coefficient of wear, 5.3; a fair cementing value, 16.6; hardness of 9.6; and a low resistance to impact, 7.0.

Sample 101, hard-pan gravel or "hill gravel"; taken from the roadside south of the Osage River near Warsaw; consisting of chert mixed with about 50 per cent of red clay. It exists in great quantities all over the County and is much used for surfacing roads. It has an excellent cementing value, 167.8.

BOLLINGER COUNTY.

The road materials found in this county are limestone which is plentiful in the west part of the county, but has not been used to any extent on the roads; and creek gravel which occurs plentifully in the north and west parts of the county and has been used some for road building.

Sample 194, magnesian limestone containing clay along the stratification planes, has a rough sharp fracture, and is easily broken into cubes; taken from an old quarry one half miles west of Lutesville on the property of A. J. Englehart. Tests show low coefficient of wear, 7.0; good cementing value, 46.6; hardness of, 9.1, which is soft; and a low resistance to impact, 6.0.

Sample 195, creek gravel from Crooked Creek one quarter of a miles east of Lutesville on the property of Geo. E. Conrad; consists chiefly of hard chert worn smooth by water; and has a fair cementing value, 14.0.

BOONE COUNTY.

The limestone quarries of this County produce three kinds of stone which have been used for road building, these are all found in the same quarry; the white crystalline limestone generally occurs in the top ledges; the blue crystalline limestone below the white and in the deeper parts of the quarry; and the chert or flint occurs in seams and pockets all through the limestone ledges. Creek gravel is found in abundance in the small streams and the old toll roads in this county have been constructed of this material mainly.

Sample 69, blue limestone with a coarse crystalline structure, containing many fossils; taken from a quarry one half mile southwest of Columbia owned by John A. Stewart. Tests show a low coefficient of wear, 5.4; excellent cementing value, 132.4; hardness of 10.1, which is soft; and a low resistance to impact, 7.0. Too soft for road metal except for the lightest traffic.

Sample 70, white limestone with a coarse crystalline structure, containing many fossils; taken from the same quarry as sample 69. Tests show a very low coefficient of wear, 3.5; good cementing value, 42.6; hardness of 13.3; and a low resistance to impact 9.0.

Sample 234, chert or flint rock, very hard and brittle; from the

same quarry as 69 and 70. Tests show a low coefficient of wear, 6.8; cementing value of 17.4. No tests were made for hardness or toughness. This sample required 105 grams of water to produce a paste in the ball mill for moulding briquettes, 90 grams is usually sufficient for most stones.

Sample 238, creek gravel from Hinkson Creek just above the bridge on Providence Road about one mile south of Columbia. Tests show a high resistance to wear, the coefficient being 15.4; and a cementing value ranging from 24.0, with 50% of Hinkson sand, to 80.6, with 25% of Hinkson sand and without sand, using only the larger pieces of gravel broken so as to pass a ¼-inch mesh, the cementing is 32.0. While the average cementing value would be considered good the authors believe the hardness of the stones and their rounded shape prevents them from binding readily under traffic until a sufficient amount of loam and clay has been carried onto the road to form a binder. With a finely crushed softer rock of good cementing value, such as the blue limestone found in this county, for a binder, it is believed a good permanent road can be constructed with this gravel.

BUCHANAN COUNTY.

Sample 16, limestone from a quarry at St. Joseph, owned and operated by Young Brothers. An eleven foot face is exposed and the crushed stone from this quarry is being used for concrete and road metal in St. Joseph and vicinity. Tests show a medium coefficient of wear, 10.2; good cementing quality, 48.6; hardness of 13.4; and a low resistance to impact, 7.0.

Sample 17, a light gray limestone of fine texture, has a rough irregular fracture, and contains numerous pits of sand and clay; taken from the quarry of the St. Joseph Rock Crushing Co. at St. Joseph, on the property of Mrs. D. Mignary. Tests show a low coefficient of wear, 7.7; good cementing quality, 32.2; hardness of 13.8; and a low resistance to impact, 5.0.

BUTLER COUNTY.

The only road materials found in this county are limestone, which has not been used much except for the manufacture of lime; and creek gravel which occurs only in the northwest half of the county and has been used very little on the roads.

Sample 181, calcium magnesian limestone, from Magruder's quarry six miles west of Poplar Bluff on the farm of W. S. Davenport. It has a crystalline structure, close texture with an occasional pit, and has a sharp fracture. Tests show a low coefficient of wear, 6.4; a good cementing value, 42.0; a hardness of 9.9; which is soft; and a low resistance to impact, 8.0.

Sample 182, creek gravel, taken from creek five and one half

miles west of Poplar Bluff on the farm of J. M. Wills; consists chiefly of fragments of chert free from sand; and has a low cementing value, 9.0.

CALDWELL COUNTY.

Sample 38, blue limestone with close texture and rough fracture; from a quarry one half mile north of Breckenridge owned by the Breckenridge Stone Co. The quarry has fifteen foot face exposed, and is on a spur track of the C. B. & Q. R. R. Tests show a low coefficient of wear, 6.1; good cementing value, 35.0; hardness of 12.3; and a low resistance to impact, 7.0.

Sample 39, gray limestone with coarse texture and rough ragged fracture; containing pits of sandstone, large crystals of calcite, and many fossils; from the same quarry as sample 38, existing above it in a six foot ledge. Tests show a low cofficient of wear, 4.7; good cementing value, 29.2; hardness of 8.3; and a low resistance to impact, 9.0.

Sample 40, bituminous limestone with a coarse open texture, mixed with sand and clay; from a quarry one half mile north of Breckenridge, owned by Mont Maddoux. The ledge is six feet thick and has black streaks all through it. This stone is used for rip rap on the C. B. & Q. R. R. Tests show a very low coefficient of wear, 0.8: and a low cementing value, 9.0; hardness of 3.4; and a low resistance to impact, 7.0.

CAPE GIRARDEAU COUNTY.

The road materials found in this county are blue limestone, which is quarried near Cape Girardeau and used on the roads and streets and for railroad ballast and riprap; white limestone quarried near Cape Girardeau and used mostly for buildings; a brown sandstone from the river bluffs north of Cape Girardeau and creek gravel which occurs plentifully in the north half of the county.

Sample 190, blue limestone from quarry two miles south of Cape Girardeau owned by Edward Hely. Tests show a medium coefficient of wear, 9.1 which is rather high for limestone; a fair cementing value, 20.6; hardness of 13.8; and a medium resistance to impact, 14.5. These tests indicate a medium road material, which is above the average limestone but probably too soft for heavy traffic.

Sample 191, brown sandstone, from quarry one half mile north of Cape Girardeau owned by Edward Regenhardt. It is fine grained, medium close texture, sharp fracture, and has been much used for building purposes. Tests show a low coefficient of wear, 7.5; a good cementing value, 40.6, which is high for sandstone; hardness of 12.5; and a low resistance to impact, 12.5, which is rather high for sandstone.

Sample 192, white limestone from quarry one mile northwest of Cape Girardeau owned by John Himmelberger. Tests show very low coefficient of wear, 5.7; good cementing value, 39.0; hardness of 10.7, which is soft; and a low resistance to impact, 12.0.

Sample 193, creek gravel, from creek bed one and one half miles northwest of Cape Girardeau on the property of Maple Wilson; composed of chert and free from earth and sand; and has a good cementing value, 32.2.

CARROLL COUNTY.

Samples of three kinds of limestone and one sample of sandstone were received from this county.

Sample 1, light gray sandstone with a coarse texture, the grains of sand being cemented together with lime, with occasional spots of brown sandstone; taken from the quarry of the Carroll County Sandstone Co. near Miama. This stone is used extensively for buildings, the Carroll County Court House being built of it; but would be a poor road metal, being entirely too soft; so the tests were made for comparison only. The tests show a very low coefficient of wear, 2.8; good cementing value, 51.6; hardness of 5.5, which is very soft; and very low resistance to impact, 7.0.

Sample 2, brown limestone, containing a large percentage of sand and occasional streaks of clay, the cementing material is iron oxide, silica and lime, it has a close texture and a rough fracture; it was obtained from a three foot ledge outcropping in the road two miles west of Carrollton on the "Ground Hog Road." The tests show a medium coefficient of wear, 9.3; a good cementing value, 26.6; hardness of 12.9; and a low resistance to impact, 10.0.

Sample 3, gray limestone, rough and nodular, containing pits of clay and sand, also large crystals of calcite imbedded in the finer mass, it has a rough irregular fracture and numerous cleavage planes running at various angles to the stratification planes. This sample was obtained from the farm of John Bailey three miles northwest of Carrollton. The ledge is only about one foot thick and extends over a large area in the north central part of the county. Tests show a low coefficient of wear, 7.1; a fair cementing value, 14.0; hardness of 10.6 which is soft; and a very low resistance to impact, 7.0.

Sample 4, dark blue limestone, very dense, with occasional streaks of calcite imbedded in it, has a smooth fracture, and is easily broken into rectangular pieces; obtained from a quarry two and one half miles northeast of Tina, owned by Dr. O. R. Edmonds. This ledge is only about ten inches thick, but above this is another ledge twenty inches thick of similar quality. This stone is quarried for foundations, water tables, and curbing. Tests show a medium coefficient of wear, 12.9; excellent cementing value, 115.8; medium hard-

ness, 14.2; and medium resistance to impact, 16.0. These tests are very high for limestone and indicate a good road metal for medium traffic.

CARTER COUNTY.

The road materials found in this county are granite, which is found at only one quarry on Current River; limestone occurs in large quantities, but has not been used on the roads; creek gravel is also plentiful, but has not been much used on the roads.

Sample 170, red granite, from an old quarry on Current River three and one half miles southeast of Van Buren on the farm of Mrs. M. Carter. Tests show a high coefficient of wear of, 14.8; good cementing value, 34.2; hardness of 19.3, which is very hard; and medium resistance to impact, 14.0. These tests indicate a good road metal.

Sample 171, magnesian limestone of close texture, containing pits which give it a honeycombed appearance; taken from R. R. cut at bluff near south end of wagon bridge between Chicopee and Van Buren. Tests show a low coefficient of wear, 7.4; fair cementing value, 19.8; hardness of 9.7, which is soft; and low resistance to impact, 11.0.

Sample 172, creek gravel taken from Current River one hundred yards below highway bridge at Van Buren, on the property of the Mo. Lumber and Mining Co.; consists of pebbles of chert, dolomite, and quartzite; and has a fair cementing value, 17.8.

CASS COUNTY.

Sample 78, white limestone with medium close texture and having a little clay mixed throughout; from Glen Parker's quarry one mile north of Pleasant Hill. The quarry has been opened to a depth of eight feet. Tests show a low coefficient of wear, 6.4; good cementing value, 43.8; hardness of 13.7; and a low resistance to impact, 6.0.

Sample 102, white limestone with close dense texture and a sharp fracture, from a quarry near Harrisonville owned by Frank Runneberger. Tests show a low coefficient of wear, 6.9; good cementing value, 45.2; hardness of 9.3; and a low resistance to impact, 12.0.

East of Pleasant Hill and Harrisonville and south of Harrisonville the formation is mostly sandstone and shale, the rest of the county has an abundance of limestone.

CEDAR COUNTY.

Sample 108, gray crystalline limestone (Burlington limestone) having a coarse dense structure and a rough fracture; from the property of R. L. Hutton on Walnut Creek two miles northwest of Eldorado Springs. This stone is found in greater quantities in the

eastern part of the county. The tests show a low coefficient of wear, 4.9; a fair cementing value, 16.0; hardness of 9.8; and a low resistance to impact, 8.0.

Magnesian limestone is found in the eastern part of the county along the streams and creek gravel is found in the streams of the eastern part but no samples of these were secured.

CHARITON COUNTY.

Sample 64, gray limestone with dense texture; obtained from the farm of C. A. Huffman, three miles northwest of Brunswick. The ledge is exposed in a cut on the Wabash R. R., no quarry exists here. Tests show a medium coefficient of wear, 12.8; good cementing value, 28.2; hardness of 10.3, which is soft; and a low resistance to impact, 11.0.

Sample 65, light brown sandstone with open texture and very soft; obtained from a quarry two miles south of Salisbury owned by Albert Hawkins. The ledge is ten feet thick. Tests show a very low coefficient of wear, 1.6; fair cementing value, 21.0; hardness of 3.1; and low resistance to impact, 5.0. A very poor road material.

CLARK COUNTY.

Sample 47, white chalky limestone having a smooth fracture and containing some streaks of brown sandstone. The specimen was weathered but was sound on the inside and seemed to have been deposited in very thin layers that adhere quite firmly together. Occurs in a four foot ledge, above ledge from which sample 48 was taken, in many places on John Willard's farm near the main line of the Santa Fe R. R. near Dumas. No quarry exists here but there is an abundance of stone of easy access. The tests show a high coefficient of wear, 13.8; good cementing value, 51.0; hardness of 10.8; and a low resistance to impact, 8.0.

Sample 48, blue limestone with very close texture and a rough fracture, and somewhat decomposed; from the same bluffs as sample 47. From 10 to 20 foot face of this stone is exposed. Tests show a medium coefficient of wear, 8.7; good cementing value, 69.8; medium hardness, 14.3; and low resistance to impact, 5.0.

Sample 49, very dark limestone with very close texture and having clay disseminated throughout; from Sam Casey's quarry on Fox River four miles north of Kahoka. The ledge outcrops for some distance along Fox River, and this stone has been used on the streets of Kahoka. Tests show medium coefficient of wear, 9.3; good cementing value, 50.8; hardness of 12.7; medium resistance to impact, 14.0.

CLAY COUNTY.

Sample 8, blue limestone having a sharp splintery fracture, dense

texture, with occasional veins of pure calcite running through it; from an old quarry belonging to W. Bagley, one and one half miles northeast of Liberty, near the road and on the bank of a small stream. The ledge is about three feet thick and rests on a bed of shale. This rock has been used on the streets of Liberty. Tests show a high coefficient of wear, 13.8; a fair cementing value, 22.2; medium hardness, 14.7; and a low resistance to impact, 10.0. The hardness and coefficient of wear are quite high for a limestone.

Sample 9, brownish gray limestone, having a smooth concoidal quartzlike fracture, with large crystals of calcite imbedded in a very close ground mass; from a quarry on the Wabash R. R. just west of South Liberty, owned by S. H. Atwood. This stone occurs irregularly in the top ledges of the quarry. Tests show a medium coefficient of wear, 9.7; a fair cementing value, 14.2; hardness of 13.8; and a low resistance to impact, 8.0.

Sample 10, blue limestone with close texture, interspersed with veins and crystals of calcite, and having a smooth fracture; from the same quarry as sample 9. The face of this quarry is from twenty to thirty feet and the crushed stone is used for ballast, concrete, and road work. Tests show a low coefficient of wear, 7.5; a fair cementing value, 14.2; hardness of 11.4; and a low resistance to impact, 6.0.

Sample 11, gray limestone, close fine texture, rough fracture, and containing a small percentage of clay and sand; from the Ettison quarry, three quarters of a mile southwest of Excelsior Springs. The quarry has about an eight foot face exposed and the crushed stone is used for macadam streets in Excelsior Springs. Tests show a low cofficient of wear, 7.0; good cementing value, 27.0; medium hardness, 14.1; and a low resistance to impact, 6.0.

Sample 12, limestone from a newly opened quarry in Excelsior Springs, owned by John Carr. Quarry has four feet face exposed and the stone is used on the macadam streets. Tests show medium coefficient of wear, 8.0; good cementing value, 36.4; medium hardness, 16.2 and a resistance to impact of 12.0.

CLINTON COUNTY.

Sample 14, limestone from J. H. Anderson's quarry on the farm of Gov. Ingles just north of Plattsburg. The ledge is ten inches thick and the stone is used for foundations and concrete aggregate. Tests show a medium coefficient of wear, 9.5; good cementing value, 43.1; hardness of 12.5; and a low resistance to impact, 8.0.

Sample 15, gray limestone, close texture, containing a small percentage of sand and clay, also streaks and large crystals of calcite; from the same quarry as sample 14. being in ledge above 14. This stone is found all along the bluffs overlooking the Smith Fork River.

Tests show medium coefficient of wear, 11.8; good cementing value, 61.0; hardness, 12:5; and a low resistance to impact, 7.0.

COLE COUNTY.

Sample 94, magnesian limestone (dolomite) with fine grain but open texture, from a quarry on Miller Street in Jefferson City, owned by the state and operated by Joseph Pope. This is the prevailing stone of the county and is found in abundance in most parts of the county. It is used for most of the building and street work in Jefferson City. The tests show a medium coefficient of wear, 8.2; and a fair cementing value, 24.6; hardness of 4.7, which is soft; and a low resistance to impact, 4.0.

Sample 95, creek gravel from Moreau Creek four miles south of Jefferson City on Moreau Road and near Greenberry Bridge; composed of chert mixed with about 40% of sand. Moreau Road is surfaced with this gravel and is in excellent condition. The tests show a good cementing value of 42.6.

COOPER COUNTY.

There is an abundance of limestone in this county and some gravel in the southern part, but no sample of gravel was obtained.

Sample 78, gray limestone with coarse grained crystalline structure and very rough fracture; from the city quarry at Boonville about three quarters of a mile down the Missouri Pacific track from the main street. This rock is used on the macadam streets of Boonville and for making concrete. It is typical of the limestone along the Mo. River in Cooper and Moniteau Counties. The tests show a medium coefficient of wear, 8.2; good cementing value, 25.2; hardness of 8.6, which is soft; and a low resistance to impact, 6.0.

Sample 79, white crystalline limestone containing large crystals of pure calcite and many fossils. It has a rough fracture. It comes from a quarry on the county road three or four miles south of Boonville, adjoining the property of Chas. Grathwohl. Tests show a very low coëfficient of wear, 3.3; very good cementing value, 92.2; hardness of 7.6; and a low resistance to impact, 5.0.

CRAWFORD COUNTY.

Limestone occurs over the county but has not been used on the roads; used for lime. "Hill gravel" is found all over the county in beds from two to ten feet thick and has been used to a limited extent on the roads. Creek gravel occurs in nearly all parts of the county and has been used some on the roads.

Sample 154, silicious limestone with coarse texture and rough fracture, containing some clay and considerably pitted; taken from a quarry one quarter of a mile northeast of Frisco depot in Steelville, owned by D. A. Houston. Tests show a very low coefficient of

wear 3.6; good cementing value, 25.6; hardness of 1.3, which is very soft; and a low resistance to impact, 8.0.

Sample 155, "hill gravel" taken from hillside one mile northeast of Steelville on land of Chas. Stough; consists of fragments of chert, very hard and showing no signs of disintegration, and has a fair cementing value, 12.2.

Sample 156, creek gravel, taken from creek one half mile southwest of Steelville on property of J. C. Campbell; consists chiefly of chert and dolomite, free from sand, and has a good cementing value, 44.6.

DADE COUNTY.

Sample 124, gray crystalline limestone with a dense close texture and good fracture; from a quarry one mile from South Greenfield, owned by the Ash Grove White Lime and Cement Co. This has been quite an important quarry but is not in use at present. This stone is found in abundance throughout the southeast quarter of the county. Tests show a low coefficient of wear, 5.8; good cementing value, 31.0; hardness of 7.4; and a very low resistance to impact, 5.0.

Sample 125, brown sandstone mixed with dolomite and flint known locally as flint boulders. The dolomite was badly disintegrated and honeycombed and the flint was cracked in many places. It is found in abundance all over the county. This sample was picked up on the roadside between Greenfield and South Greenfield. Tests show a low coefficient of wear, 4.8; a fair cementing value, 12.8; hardness of 12.3; and a low resistance to impact, 9.0.

Creek gravel is found in abundance in all the streams and is the material generally used for road surfaces, no sample of this was obtained.

DAVIESS COUNTY.

Limestone is the only road material found in this county, four samples of which were sent in from the vicinity of Gallatin.

Sample 29, blue limestone, fine grained, close texture, with occasional veins of calcite running through it; from a quarry in the north part of Gallatin owned by William Rulong. The stone is being used for concrete aggregate. Tests show a medium coefficient of wear, 9.7; fair cementing value, 17.0; hardness of 13.8; and a medium resistance to impact, 14.5. These tests are above the average for limestone.

Sample 30, blue limestone from an old quarry one mile south of Gallatin owned by Wood H. Hamilton. The top ledge is eight inches thick, the second eleven inches thick and the third fourteen inches thick. Tests show a medium coefficient of wear, 8.7; good

cementing value 38.6; hardness of 13.4; and a low resistance to impact, 11.0.

Sample 31, light gray limestone with fine close texture, having streaks of clay and sand; from a quarry owned by the city of Gallatin and near the Rock Island depot. A small crusher is operated here and the stone is used on the streets of Gallatin. Tests show a medium coefficient of wear, 8.8; a fair cementing value, 19.6; medium hardness, 14.7; and a low resistance to impact, 8.0.

Sample 73, white limestone of close texture; from the quarry of Robinson and George at Gallatin, owned by A. R. George. The sample was crushed before shipping and was considerably abraded by shipment. Tests show a medium coefficient of wear, 8.0; good cementing value, 64.0; hardness of 10.7; and medium resistance to impact, 14.0.

DEKALB COUNTY.

Limestone is the only road metal found in this county, three samples of which were secured in the vicinity of Maysville.

Sample 35, clayey limestone, buff color, close fine texture, and a sharp flinty fracture; from a quarry on J. C. Sparling's place two miles southeast of Maysville. It is found in ledges ten to twelve inches thick and it becomes harder on exposure to the weather. Tests show medium coefficient of wear, 11.7; a fair cementing value, 16.6; medium hardness, 14.3; and a low resistance to impact, 10.0.

Sample 36, blue limestone of coarse texture but very dense, contains large crystals of calcite, and has a rough ragged fracture; from the same quarry as No. 35. Ledge is from two to three feet thick. Tests show medium coefficient of wear, 8.8; a fair cementing value, 14.8; hardness of 11.3; and a low resistance to impact, 8.0.

Sample 37, dark gray limestone, fine grained, containing deposits of sandstone and clay, and having a ragged fracture; from a quarry one mile east of Maysville, owned by Jacob Winter. The ledge is twelve to eighteen inches thick. This stone occurs in several parts of the county. The tests show a medium coefficient of wear, 8.0; a fair cementing value, 11.6; hardness of 10.2; and a low resistance to impact, 7.0.

DENT COUNTY.

The road materials found in this county are limestone, which occurs plentifully but has not been much used for either building or road purposes; "hill gravel", which is plentiful and said to be highly satisfactory when it has been used on the roads; and creek gravel, which occurs plentifully only in the streams of the eastern portion of the county, the Meramec River affording an almost inexhaustable supply of this material.

Sample 150, limestone with close texture and rough fracture; from a quarry three quarters of a mile northeast of Salem, owned by Chas. Lust. Tests show a medium coefficient of wear, 9.5; a fair cementing value, 22.2; hardness of 11.5; and low resistance to impact, 12.0.

Sample 151, "hill gravel", taken from roadside three quarters of a mile northeast of Salem; consisted chiefly of fragments of chert mixed with clay; and showed a good cementing value, 31.2. This material occurs in beds from five to eight feet thick.

Sample 152, creek gravel, taken from the Meramec River six miles northeast of Salem on the farm of L. H. Dent; consisted of pebbles of chert, dolomite and rhyolite, very hard and smooth, and sand. Test showed a very good cementing value, 75.8.

FRANKLIN COUNTY.

Sample 142, white magnesian limestone from quarry owned by the city of Washington, located one mile west of the Missouri Pacific depot; this stone has been used in the macadam streets of Washington and in some buildings, and occurs in considerable quantities in this vicinity. The tests show a medium resistance to wear, 8.3; a fair cementing value, 19; hardness of 12.6, which is soft, and a medium resistance to impact, 15.

Sample 143, white limestone containing sand and clay disseminated throughout, has a rough fracture and presents a somewhat pitted appearance; taken from a quarry one mile east of Rock Island depot at Union, owned by L. B. Bruck. It occurs in quantities and is used principally for buildings. The tests show a low resistance to wear. 4.4; a fair cementing value, 23.6; hardness of 12.1, which is soft; and a low resistance to impact, 10; it is therefore considered a poor road material.

Sample 144, bank gravel taken from gravel bank about one and one half miles east of the court house at Union, owned by Jesse Ekey; consists of chert, quartsite and sand, mixed with red clay; occurs in large quantities and is much used as a road material. It has a good cementing value, 41.0 probably due to the red clay.

GASCONADE COUNTY.

Sample 140, magnesian limestone (cotton rock) from a quarry owned by the City of Hermann one mile south of the Missouri Pacific depot; it has a fine grained opened texture with clay disseminated throughout, rough fracture, and the stratification planes well defined; occurs extensively and is used on the streets of Hermann and on the roads around Hermann. The tests show a low coefficient of wear, 6.8; a good cementing value, 58.4; hardness of 12.7, which is soft, and a low resistance to impact, 9.0.

Sample 145, magnesian limestone from a quarry on the farm of Gustave Holychuch, three miles north of Owensville; it has a fine grained open texture with clay disseminated throughout, smooth fracture; occurs in quantities and is used both for road and building purposes. The tests show a low resistance to wear, 6.3; a good cementing value, 71.2; medium hardness, 15.2; and a medium resistance to impact, 13.5.

Sample 146, creek gravel taken from creek three miles north of Owensville on the farm of Gustave Holychuch; it consists of hard pebbles of chert and dolomite mixed with sand. The test showed a good cementing value, 36.2. This gravel occurs plentifully in the southern part of the county, but has not been much used for road building purposes.

GENTRY COUNTY.

Sample 26, gray limestone with a close fine texture, having clay disseminated throughout, and a smooth sharp fracture; from Dan Blatcher's place, one and one half miles south of Evona. This rock is used in Albany for concrete aggregate, but is not extensively quarried. Tests show a low coefficient of wear, 5.9; excellent cementing quality, 105.8; hardness of 8.2; and a low resistance to impact, 10.0.

Sample 27, brownish gray limestone with rather open texture, containing streaks of calcite, and having a smooth sharp fracture; from the farm of S. M. Austin, three quarters of a mile southwest of McFall. The ledge is two or three feet thick and lies beneath a bed of sandstone. Tests show a medium coefficient of wear, 12.1; good cementing quality, 54.6; hardness of 12.7; and a medium resistance to impact, 14.5.

Sample 28, dark blue limestone with a dense close texture, having occasional large crystals imbedded in it, and a smooth sharp fracture; from the same quarry as 27 and lies beneath it. The ledge is only eight or ten inches thick. Tests show a medium coefficient of wear, 9.0; good cementing value, 32.6; medium hardness, 14.1; and a low resistance to impact, 7.0.

GREENE COUNTY.

Sample 126, gray crystalline limestone, coarse grained, containing many large crystals of calcite so interlocked as to give it a granitic appearance. It has a rough fracture and a few suture joints. Obtained from Horton's quarry in Springfield. This stone is found in various localities over the county. The tests show a low coefficient of wear, 5.2; good cementing value, 46.2; hardness of 6.8; and a low resistance to impact, 5.0.

Sample 127, cherty dolomite, or surface flint rock, containing all gradations from dolomite to chalk, white for the most part, the red

iron oxide stains showing occasionally. Picked up on roadside three miles west of Springfield. It is found all over the county scattered loosely over the fields and piled up on the roadsides. It has been used on several miles of road near Springfield and is very satisfactory. Tests show a low coefficient of wear 5.9; a fair cementing value, 12.4; medium hardness, 15.5; and a resistance to impact of 12.5. For remarks on the hardness and toughness tests of such material see Jasper county. Sample 112.

Sample 128, gravel from James River eight miles southwest of Springfield; consists chiefly of rounded pebbles of chert, very hard and ranging in size from two inches in diameter to fine sand; and the test showed a cementing value of 25.6.

This gravel was used in building the government road from Springfield to the National Cemetery. This road is in fine condition. Gravel similar to this is found in all of the good sized creeks in the county.

GRUNDY COUNTY.

Sample 34, brown limestone with coarse texture, rough fracture, and mixed with sand and clay; from a quarry one mile southwest of Trenton, owned by Harry Hertzog. A face of fifteen feet is exposed in this quarry. It is used for macadam streets and concrete, and is said by the County Highway Engineer to be a fair sample of the limestone found in this county. Tests show a low coefficient of wear, 6.1; good cementing value, 26.8; hardness of 6.7; and a low resistance to impact, 6.0.

HARRISON COUNTY.

Sample 23, limestone from an old quarry belonging to Dean Speery located southwest of Bethany. Four foot ledge exposed, more beneath, little stripping is necessary. Tests show a low coefficient of wear, 5.9; excellent cementing value, 112.6; hardness of 10.2; and low resistance to impact, 9.0.

Sample 24, limestone from a quarry about three quarters of a mile southwest of Bethany on the property of A. H. Flint, leased to the city of Bethany, the crushed rock being used for concrete. The ledge is ten feet thick and has eight feet of stripping. Tests show a low coefficient of wear, 6.9; good cementing value, 33.8; medium hardness, 16.8; and a medium resistance to impact, 13.0.

HOLT COUNTY.

Sample 21, gray limestone, fine texture, rough fracture, and contains sand, clay, and large crystals of calcite; from a small quarry owned by Robert Walters, one and one half miles south of Oregon. The crushed rock is used to a small extent on the streets of Oregon. The tests show a low coefficient of wear, 7.1; excellent cementing

value, 103.8; hardness of 9.8; and a low resistance to impact, 7.0.

Sample 22, blue limestone, close texture, splintery fracture, with large crystals of calcite imbedded, and clay disseminated throughout; from a small quarry in Forest City owned by Ira Hall. The ledge is ten feet thick, but requires considerable stripping. Tests show a low coefficient of wear, 7.6; good cementing value, 51.4; hardness of 11.4; and medium resistance to impact, 13.0.

HOWELL COUNTY.

The road materials available in this county are creek gravel, which occurs plentifully in all stream beds; and the surface or field stones of chert which are plentiful in most localities.

Sample 75, chert, field stones from Fruitville Farm Co. The tests show a low coefficient of wear, 5.9; an excellent cementing value, 206.8; a hardness of 10.2, which is soft; a low resistance to impact, 9.

Sample 76, similar to 75, and from same locality. Tests show low coefficient of wear, 4.9; excellent cementing qualities, 277.4; hardness of 9.6, which is soft; and low resistance to impact, 7.5.

Sample 165, creek gravel taken from creek one quarter of a mile west of Willow Springs on the farm of D. S. Ferguson; consists of chert and cherty dolomite, mixed with sand; is said to be a fair representative of the gravel that occurs in the stream beds all over the county; and has been used to a very limited extent on the roads. Tests show a good cementing value, 37.2. This gravel is probably much harder and tougher than samples 75 and 76 and would wear much better, but as the field stones show such excellent cementing qualities it would seem that a combination of gravel and finely crushed stones would make a better road material than either one taken separately.

Sample 166 is a white sandstone from a quarry three and one half miles west of Willow Springs owned by I. D. McLucas. This stone is used for building only, and has no qualities to recommend it as a road material, so the tests were made only for comparison. Its coefficient of wear is exceedingly low, 0.8; a very low cementing value, 4.4; very soft, 4.4; and its resistance to impact is exceedingly low, 2.0.

IRON COUNTY.

There is a large variety of road material in this county. Red granite occurs abundantly in the vicinity of Graniteville and the refuse from the granite quarries has been used on some of the roads near Graniteville. Porphyry is plentiful in many parts of the county. Refuse from the old iron mines at Pilot Knob; there is a considerable amount of this material, but it has not been used for road purposes. Limestone is plentiful in the northern part of the county and creek gravel occurs in the stream beds all over the county. At Shepard's

mountain near Ironton there is a large amount of so-called "rotten granite" which seems to be an excellent binder for road surfaces.

Sample 212, red granite with large interlocking crystals, from the Syenite Granite Co's. quarry at Graniteville. Tests show a medium coefficient of wear, 10.4; good cementing qualities, 40.8; medium hardness, 14.4; and a medium resistance to impact, 19.0.

Sample 213, red hematite iron ore, close texture, metallic luster and very heavy, taken from the dump of old iron mine on north side of Pilot Knob Mountain about one mile northeast of Ironton. There is a good deal of this mine refuse at this place. Tests show a low coefficient of wear, 7.1; good cementing value 36.2; hardness of 17.2; and a medium resistance to impact, 13.0.

Sample 214, magnesian limestone, medium close texture, somewhat pitted giving it a slightly honeycombed appearance, it has a sharp rough fracture and a sandy touch; taken from hillside one mile southwest of Graniteville on the property of Pilot Knob Mining Co. Tests show a low coefficient of wear, 7.7; good cementing value, 61.0; hardness of 12.8; and medium resistance to impact, 13.5.

Sample 215, porphyry, a very dense, hard, ingenous rock having a fine ground mass with large dark crystals imbedded, sharp fracture, and red color; taken from hillside three and one half miles northwest of Ironton on the property of Pilot Knob Mining Co. Tests show a medium coefficient of wear, 11.4; very good cementing value, 78.8; medium hardness, 15.3 and a high resistance to impact, 20.5. These tests indicate an excellent road material.

Sample 216, creek gravel, taken from creek bed near the Iron Mountain R. R. about one half mile north of Ironton; consists chiefly of chert and quartz mixed with sand; and has a fair cementing value, 22.8.

Sample 240, "rotten granite", reddish in color and easily broken in pieces by the hands, from Shepard's Mountain one quarter of a mile northwest of Ironton. It has an excellent cementing value, 390.0, which indicates that it would be an excellent binding material. This sample was sent in by Curtis Hill, State Highway Engineer.

JACKSON COUNTY.

This county has an abundance of limestone all over the county and a great many macadam roads have been built of this material.

Sample 83, grayish blue limestone with a medium close texture and ragged fracture, containing numerous deposits of pure calcite, which has a weakening effect on the stone. Taken from the upper strata of a quarry on the east side of Independence, owned by G. W. Shaw. The exposed face of this quarry is thirty five feet and the crushed stone is being used on the roads in the vicinity of Independ-

ence. The tests show a low coefficient of wear, 5.8; good cementing value, 65.5; hardness of 9.9; and a low resistance to impact, 8.0.

Sample 84, bluish gray limestone of medium close texture, containing a large percentage of clay deposited in the layers throughout. Taken from the lower strata of the same quarry as sample 83. The tests show a low coefficient of wear, 7.3; good cementing value, 25.4; hardness of 13.8; and a low resistance to impact, 6.0.

Sample 85, blue flinty limestone with a dense texture and sharp fracture; from an old quarry along the road on Sugar Creek about three miles northwest of Independence. This quarry was opened about 1900 to obtain rock for a macadam road in that vicinity and the road built of this rock is said to be still in good condition. The tests show a low coefficient of wear, 7.8; excellent cementing quality, 107.8; medium hardness, 14.5; and a low resistance to impact, 9.5.

Sample 86, blue limestone, composed of large crystals of calcite imbedded in a fine ground mass which contains a large per cent of clay, the fracture is ragged. From Wagner's quarry on the Blue Springs road six miles east of Independence. This stone is now being used on the Blue Springs Road. The tests show a low coefficient of wear, 6.7; good cementing value, 27.0; hardness of 6.8, which is soft; and a low resistance to impact, 4.0.

JASPER COUNTY.

Sample 111, pit gravel from near Spring River and the gravel road. on the property of Geo. McDaniel two and one half miles east of Carthage. Sample consisted of chert and cherty dolomite mixed with about 20% of clay; and showed a good cementing value of 83. This gravel is found in many localities throughout the county, but not in such abundant quantities as on the hillsides along Spring River; and it is a favorite road material in the county. This same gravel without the clay is found in all the stream beds, but no sample of this creek gravel was obtained.

Sample 112, cherty dolomite, known locally as "cotton rock." It contains all gradations from dolomite to chalk, is very porous and the outside is colored red with iron oxide. It occurs in loose fragments and boulders in quantity in various places; this sample was taken from the Ammon's Farm near Carthage. This stone is crushed and used on macadam roads. The tests show a low coefficient of wear, 3.9; a low cementing value, 10.0; hardness of 11.1; and a medium resistance to impact, 15.0. In such material as this the cores for making the hardness and toughness tests are necessarily cut from the larger and more solid parts of the stone, and therefore the hardness and toughness tests probably run considerably higher than the average hardness and toughness of such material.

Sample 114, gray crystalline limestone with uniform close tex-

ture, rough fracture, has a few suture joints and will take a high polish. From the Carthage Superior Marble and Limestone Co.'s quarry at Carthage. This stone is widely distributed over the county and it is largely used as a building stone. It is known throughout the country as Carthage stone. The tests show a low coefficient of wear, 6.8; good cementing value, 41.6; hardness of 12.1; and a low resistance to impact, 7.0.

Sample 239, "Chats", a finely crushed flint rock, which is the refuse from the lead and zinc mines. It is a hard flinty material and is largely used on macadam roads; but owing to the sample being finely crushed the only test that could be made was for cementing value, which is 25.0.

JEFFERSON COUNTY.

Limestone is plentiful in the south part of the county, and has been crushed and used on the roads; and creek gravel is plentiful in most parts of the county.

Sample 219, magnesian limestone with a fine grained open texture, rough fracture, white in color, has clay between the stratification planes along which it readily parts; taken from quarry one mile southeast of Hillsboro, owned by Joseph Hoken. Tests show medium coefficient of wear, 8.2; fair cementing value, 15.6; hardness of, 6.8; and a low resistance to impact, 5.0.

Sample 220, creek gravel, taken from creek bed about one hundred yards west of Iron Mountain R. R. station at Victoria; consists of pebbles of chert and cherty dolomite free from sand and earth, and has a fair cementing value, 22.8.

JOHNSON COUNTY.

The only road metal found in this county is limestone; there is no gravel in the county. Warrensburg is situated on an immense sandstone ridge, but this sandstone is too soft for road purposes.

Sample 88, blue limestone with close texture and sharp smooth splintery fracture, containing a few large crystals of calcite imbedded; from a quarry on Judge Bradley's farm about two and one half miles northeast of Warrensburg. This sample was sent in by David Mohler, the County Highway Engineer, and is typical of the rock in the central part of the county. It occurs in ledges from one to eight feet thick, generally about three feet, and it lies just above the coal beds. The tests show a medium coefficient of wear, 8.5; a good cementing value, 36.4; medium hardness, 15.8; and a medium resistance to wear, 13.0.

KNOX COUNTY.

Sample 51, a coarse crystalline limestone of dark color and having a rough fracture; taken from a small quarry on the farm of John

W. Vaughn, two miles southwest of Edina. This sample is a representative of the stone of Knox county. Tests show a low coefficient of wear, 4.8; good cementing quality, 55.8; hardness of 8.5, which is soft; and a low resistance to impact, 11.0 These tests indicate that this stone is too soft and brittle, for road metal, except for very light traffic.

LACLEDE COUNTY.

Sample 131, cherty dolomite having a close texture, and containing numerous small cavities and cracks running through it; taken from a quarry on the property of Mrs. E. L. Greenlief in Lebanon. This stone is found throughout the county. Tests show a low coefficient of wear, 5.1; good cementing value, 51.2; medium hardness, 15.5; and a medium resistance to impact, 13.0.

Sample 132, creek gravel from creek on the farm of Mr. Shoemaker three and one half miles from Lebanon; consists chiefly of pebbles of chert and about 30% of sand, it is very fine, 75% passing a ½ inch mesh. It has not been used on the roads. Tests show a good cementing value, 56.

Surface chert or flint rock is also found in great abundance; for tests on this material see report on Pulaski and Webster counties.

LA FAYETTE COUNTY.

Sample 81, blue shaley limestone having a nodular structure and irregular fracture; from a quarry one half mile west of Lexington, owned by William Greer. This rock occurs in ledges from three to four feet thick and lies just above coal beds; it is also found in the hills facing the Missouri River. The sample was much weathered and badly disintegrated. Tests show a low coefficient of wear, 4.8; good cementing value, 71.4; hardness of 8.9; and a low resistance to impact, 6.0.

Sample 82, gray limestone, known as Bethany limestone, open texture, rough fracture, and containing a little iron oxide, from an old quarry on the Laura A. Nowell Estate two miles south of Lexington. This quarry shows an exposed face of seven feet but appears to go much deeper and covers an area of one square mile. This same stone is found in large quantities on the Greenton and Powell ridge from Odessa to Greenton. The tests show a medium coefficient of wear, 9.1; good cementing value, 51.4; hardness of 13.7; and a low resistance to impact, 7.0.

LAWRENCE COUNTY.

Sample 121, gray crystalline limestone, coarse grained, having a rough fracture and somewhat crumbly; from a quarry on the Gibbs estate a short distance north of Mt. Vernon. A thirty foot ledge is exposed and contains pockets of chert. Tests show a very

low coefficient of wear, 3.4; good cementing value, 34.6; hardness of 10.5; and low resistance to impact, 4.0.

Sample 122, cherty dolomite, containing all gradations from dolomite to chalk. The chert is pitted and honeycombed and red in color along its parting planes. The stone in general is a grayish blue color. This sample was taken from the property of Sherman Mundy, one half mile north of Mt. Vernon. It is found as boulders scattered in fragmental deposits on the upland. Tests show a very low coefficient of wear, 2.4; a good cementing value, 37.6; medium hardness, 15.8; and a low resistance to impact, 11.0. For a note of the hardness and toughness tests of such material, see Jasper county Sample 112.

Sample 123, creek gravel from Mill Creek just north of Mt. Vernon; consists of pebbles and fragments of chert mixed with sand and clay. The fragments show some signs of disintegration. It has a cementing value of 36.

Pit gravel, or hill gravel, is also found in this county; but no sample of this was obtained.

LEWIS COUNTY.

Only one sample, No. 50, was obtained from this county; it is a blue laminated limestone taken from the farm of George Onsley near Canton; no quarry exists here, but there is an abundance of loose rock which has been used on the streets of Canton. Tests show a low coefficient of wear, 6.8; a good cementing quality, 31.4; hardness of 8.4, which is soft; and a low resistance to impact, 11.5. These tests indicate that this stone is too soft and brittle for a good road metal.

LINCOLN COUNTY.

Sample 62, white limestone with large interlocking crystals and a few large fossils; from the quarry of the Crystal Carbonate Lime Co. at Elseberry, Missouri, which has a thirty-five foot quarry face exposed. The sample was of crushed stone, so seventy-five pieces were required for the abrasion test and the stone had been considerably abraded by shipment. Tests show medium coefficient of wear, 12.9; excellent cementing value, 107.0; hardness of 13.5, which is high for limestone; and a low resistance to impact, 11.0.

Sample 63, clayey limestone with rather open texture; from a quarry owned by John Taylor, located near the St. L. &. H. R. R. track at Troy. The ledge is five feet thick and the stone is used on the streets of Troy. Tests show a coefficient of wear of 7.9; good cementing value, 52.0; hardness of 11.4; and a low resistance to impact, 10.0.

LINN COUNTY.

Sample 41, blue limestone with close fine texture; taken from a quarry on the farm of P. D. Bundas five miles north of Linneus. The ledge is three feet thick and free from seams. It has never been used for road purposes. Tests show a medium coefficient of wear, 11.1; good cementing value, 38.8; medium hardness, 14.6; and low resistance to impact, 11.0. With the exception of cementing quality, these tests are above the average for limestone.

Sample 42, blue clayey limestone with close texture and ragged fracture; obtained from a four foot ledge on the farm of Charles Schoess one mile west of Linneus. Tests show a low coefficient of wear, 5.9; a fair cementing value, 13.2; hardness of 8.5; and a low resistance to impact, 9.0.

LIVINGSTON COUNTY.

Sample 71, brown sandstone, coarse grains cemented together with iron oxide and lime; from the farm of J. N. Roberts, two miles north of Mooresville. This stone exists in limited quantities and is used for foundations only. The tests show a very low coefficient of wear, 2.1; excellent cementing value, 139.4; hardness, 0.0, very soft; and very low resistance to impact, 4.0. This stone could not be used on road surfaces except as a binder for a harder rock or gravel.

Sample 72, white limestone having a close texture, smooth fracture and containing a small per cent of clay disseminated throughout; obtained from the farm of Jas. N. Roberts, two miles north of Mooresville. This stone has not been used for road purposes, but a large quarry could be developed here, the ledge is 10 feet thick. The tests show a medium coefficient of wear, 9.7; a very good cementing value, 93.4; hardness of 13.8, which is high for limestone; and a low resistance to impact, 8.0.

MACON COUNTY.

Sample 53, blue limestone having a fine dense texture and splintery fracture; from a quarry one and one half miles southwest of Macon owned by William Ring. The ledge is two and one half feet thick and the stone has been used principally for concrete aggregate. Tests show a medium coefficient of wear, 9.5; good cementing quality, 34.8; hardness of 11.7; and a low resistance to impact, 8.0

MADISON COUNTY.

There is quite a variety of road material in this county. Limestone is plentiful over the county, but has not been much used on the roads; rhyolite and granite are plentiful in the vicinity of and to the west of Fredericktown; kaolin, or rotten granite, occurs in

large quantities three and one half miles west of Fredericktown; "chats" from the lead mines and creek gravel.

Sample 196, silicious limestone, mineral bearing, containing green oxide of copper, red oxide of iron, and said to contain traces of gold, it contains numerous small pits which are generally empty, some being filled with iron oxide. Sample taken from hillside three and one half miles west of Fredericktown on the property of W. J. Holliday. Tests show a medium coefficient of wear, 9.3; good cementing value, 56.0; hardness of 16.2, which is medium; and low resistance to impact, 8.0.

Sample 197, rhyolite, from same locality as sample 196; consisting of quartz crystals imbedded in a fine ground mass, the texture is very dense, the fracture sharp and rough, and the color is pink. Tests show a very high resistance to wear, 22.1; good cementing value, 49.2; hardness, 18.1; and a high resistance to impact, 26.0.

Sample 198, kaolin, or rotten granite, the orthaclase and mica have disintegrated leaving a porphyritic structure with quartz imbedded in the decomposed matrix; it is soft and has a chalky touch. This sample was taken from a hill three and one half miles west of Fredericktown on the farm of W. J. Holliday, a large hill here is composed almost wholly of this material. At the point where the sample was secured a quantity of the material had been blasted out exposing a face about 20 feet high. The rock exposed in this face varied in color from almost pure white to a pink. It has been used to a small extent on roads and is said to make a good surface. The tests show a very low coefficient of wear, 2.6; very good cementing value, 78.4; hardness of 9.2; and a low resistance to impact, 6.5. These tests indicate that this material would make an excellent binder for a harder road material.

Sample 199, red granite, composed of small crystals and having a rough fracture; taken from hillside one mile west of Fredericktown on the property of George Lampher, Jr. Tests show a high coefficient of wear, 16.0; fair cementing value, 20.8; medium hardness, 16.8; medium resistance to impact, 19.0.

Sample 200, creek gravel, from creek in Fredericktown on the property of Z. J. Berryman; consists chiefly of chert and sand; and has a fair cementing value, 12.8.

Sample 202, "chat", from Mine La Monte Lead and Smelting Co. two and one half miles west of Fredericktown; it is crushed very fine and has a low cementing value, 9.6.

MARIES COUNTY.

The road materials found in this county are creek gravel, which occurs plentifully, but not used much on the roads; the so-called "hill gravel" which is a very brittle flint mixed with a considerable

amount of clay, found on hillsides in beds from one foot to several feet in thickness, it is said to be more plentiful in the east than in the west half of the county, and has been the principal road building material in the county; also pitted dolomite which occurs plentifully and is used extensively for buildings, but not much for roads.

Sample 147, "hill gravel" taken from public road one half mile east of Vienna; consists of chert, badly disintegrated and very brittle, mixed with clay. Tests show a good cementing value, 26.4.

Sample 148, creek gravel, from Fly Creek one mile west of Vienna; consists of chert, cherty dolomite, and quartzite, free from sand. Test shows a low cementing value, 5.8.

Sample 149, magnesian limestone (pitted dolomite); from quarry two miles north of Vienna owned by Andrew Weidinger; it has an open texture, nodular structure, containing clay and sand around the nodules, and is very brittle. Tests show a very low coefficient of wear, 0.8; a good cementing value, 36.0; hardness of 5.1, which is very soft; and a low resistance to impact, 6.5. This stone might be used as a binding material with the creek gravel, but its other qualities are too poor for road purposes.

MARION COUNTY.

The road materials found in this county are limestone, which is abundant in the vicinity of Palmyra and Hannibal; creek gravel, which is abundant along the entire course of the North River, a distance of forty eight miles; and a hard-pan, or bank gravel.

Sample 54, white limestone with a coarse crystalline structure and containing fossils and deposits of chert; taken from "North Cut" on the C. B. & Q. railroad two and one half miles north of Palmyra. The ledge is from fifty to seventy-five feet thick, alternating chert, or flint, and limestone. Tests show a low coefficient of wear, 5.8; very good cementing quality, 87.4; hardness of 9.6, which is soft; and a low resistance to impact, 10.0.

Sample 55, creek gravel from North River near Palmyra; consisting of pebbles of sheet limestone and quartz mixed with about 40% of sand. The pebbles are very hard and smooth and range in size from 1½ to ¼ inch in diameter. It has only a fair cementing value, 14.8. This gravel would probably make a good road surfacing material if some of the sand were replaced by finely crushed limestone like sample 54 to make it bind readily.

Sample 56, light gray limestone having a coarse crystalline structure, from a quarry operated by Huston and Bland, located on the high bluff overlooking the Mississippi River just south of Hannibal. This quarry has a face of forty feet and six feet of stripping, and the stone is crushed and used by the city of Hannibal for macadam and concrete. The tests show a low coefficient of wear,

4.6; good cementing quality, 28.2; hardness of 12.6; and a low resistance to impact, 12.5. These tests indicate that the stone is harder and tougher than the average limestone, but its low resistance to wear indicates that it is not a good road material, except for very light traffic.

Sample 77, hard-pan gravel, or bank gravel, taken from a cut on the C. B. & Q. railroad two and one half miles north of Palmyra; it lies just above the ledge of rock from which sample 54 was taken and is recommended by the County Engineer of Marion county as an excellent binder for this stone. It consists of a reddish brown clay mixed with about 40% of chert fragments. The clay is very plastic and sticky when wet and becomes very hard and tough upon drying. It has a very high cementing value, 180.8.

MERCER COUNTY.

Sample 32, blue limestone from an old quarry once operated by the Rock Island R. R. and owned by John Buren, located three or four miles south of Princeton. This sample was taken from the top ledge beneath which was a layer of slate and beneath the slate is a series of ledges of sandy limestone four to ten feet thick, similar to sample 33. Tests show a medium coefficient of wear, 9.1; good cementing value, 41.2; hardness of 13.6; and a low resistance to impact, 7.0.

Sample 33, white limestone, fine close texture, rough fracture, with occasional streaks of sand and clay; from a quarry owned by T. W. Ballew near Princeton. This rock is representative of the rock in this county and it is plentiful. Tests show a medium coefficient of wear, 8.7; good cementing value, 38.0; hardness of 11.8; and a low resistance to impact, 8.0.

MILLER COUNTY.

Sample 96, hard-pan gravel, or "hill gravel", taken from the roadside at north edge of Tuscumbia; consists of fragments of chert badly disintegrated and mixed with a sticky red clay; and has a very remarkable cementing quality, 317. This material occurs throughout the county and has been used for surfacing the road in a rough way, a drag being used.

Sample 97, creek gravel from Osage River at Tuscumbia; consists of chert, cherty dolomite, and quartzite mixed with sand and earth; and has a fair cementing value, 16.4. Gravel is found in abundance in all of the streams of the county; but that found in the smaller streams seems to be made up of larger stones and has not so much sand as that found in the Osage River.

Sample 98, white magnesian limestone or cherty dolomite, known locally as "cotton rock", fine grained and open texture; taken from the roadside one mile south of Eldon on the Tuscumbia road. The same stone is found in the Osage River bluffs and probably in other

parts of the county. The tests show a low coefficient of wear, 7.4; good cementing value, 29.4; hardness of 4.1, which is soft; and a low resistance to impact, 5.0.

MONITEAU COUNTY.

The only sample of road material received from this county was creek gravel which is found everywhere in the county and has been used on the roads near California, Mo.

Sample 93, creek gravel, from Brush Creek near California; composed of pebbles and fragments of chert, very hard and smooth; and has a good cementing value, 61.2.

Limestone is plentiful all over the county; that near the Missouri River is like sample 78, Cooper county, and that in the interior of the county is probably like the limestone of Pettis county.

. MONROE COUNTY.

Sample 66, white limestone with close texture; from the quarry of William Davis, one mile west of Paris. The quarry has a face of fifteen feet and considerable flint occurs in the limestone. Crushed rock from this quarry is used upon the roads in this locality. Tests show a low coefficient of wear, 4.7; excellent cementing value, 138 8; hardness of 3.5, which is very soft; and a very low resistance to impact, 4.0.

Sample 67, white limestone with open texture and containing streaks of sand and clay and large crystals of calcite; from the quarry of L. Hennings one half mile northeast of Paris. Tests show a low coefficient of wear, 5.1; good cementing value, 37.2; hardness of 5.1, which is soft, and a low resistance to impact, 7.0.

Sample 68, creek gravel from Elk Fork at the Mexico Bridge four miles south of Paris; consists chiefly of chert mixed with limestone, quartz, and sand; it is very fine, more than 50% of it passes a ½ inch mesh, while some pebbles are 2 inches in diameter. It is found in great abundance along Elk Fork, and is used to a great extent

a good cementing value, 39.

COUNTY.

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sembling that of neat cementing mortar, has a few large crystals of calcite imbedded, and has a smooth sharp fracture; from a quarry three miles southwest of Montgomery City owned by B. A. Donaldson. This stone is used on the roads about Montgomery City. Tests show a low coefficient of wear, 7.5; excellent cementing quality, 117.2; hardness of 4.5, which is very soft; and a low resistance to impact, 5.0.

MORGAN COUNTY.

Sample 99, creek gravel from little Gravois Creek about one and one half miles south of Versailles; consists of chert, dolomite and cherty dolomite; and has a fair cementing value, 23.2. This gravel is found in abundance all over the county and is used almost exclusively for road building. There is also some "hill gravel" in the county which is the same material as the creek gravel with the addition of clay; but no sample of this was obtained. Magnesian limestone is also found in this county but is very soft and has been found unsatisfactory for road purposes.

NEWTON COUNTY.

Sample 115, gray crystalline limestone, close texture, rough fracture, and full of suture joints; from an old quarry on the property of John Martin, just across Hickory Creek east of Neosho. This stone is found all over the county. Tests show a medium coefficient of wear, 8.7; a fair cementing value, 22.8; hardness of 12.8; and a resistance to impact of 12.0.

Sample 116, creek gravel from Hickory Creek near Neosho; composed of pebbles and fragments of chert, very hard and ranging in size from 2 inches in diameter to fine sand; and having a good cementing value, 72.

Pit gravel similar to that found in Jasper county, sample 111, is also found in Newton county.

Sample 117, cherty dolomite, known locally as "cotton rock," and similar to sample 112, containing all gradations from dolomite to chalk. A portion of the sample was honeycombed and pitted and had a reddish brown color. Taken from the roadside about one mile southwest of Neosho. This material is found in large quantities throughout the county. The tests show a very low coefficient of wear, 2.8; good cementing value, 63.2; hardness of 12.5; and a low resistance to impact, 10.0. The badly weathered condition of the sample accounts for the low coefficient of wear. For remarks on the hardness and toughness of this material see Jasper county, sample 112.

OSAGE COUNTY.

There is a plentiful supply of "cotton rock" (limestone) in the

north part of the county which has been crushed and used on the roads to a limited extent. Pitted dolomite (Jefferson City formation) occurs plentifully in the south half of the county but has been used only for buildings. Creek gravel is plentiful in most parts of the county and has been used some for road surfacing.

Sample 137, white magnesian limestone, known as "cotton rock", it has a fine open texture, and smooth fracture; taken from quarry, five miles south of Bonnots Mill, owned by August Parting. Tests show a low coefficient of wear, 4.5; good cementing value, 28.4; hardness 6.7, which is very soft; and a very low resistance to impact, 6.0. These tests indicate a low grade road metal.

Sample 138, creek gravel taken from bed of Loose Creek about one half mile south of Loose Creek P. O. on the land of Theodore Parting; it consists of soft pebbles of chert and dolomite and sand, ranging from 2 inches in diameter to fine sand, and has a very good cementing value, 80.2.

Sample 139, magnesion limestone (dolomite), fine grained, medium close texture, nodular structure, with clay disseminated throughout; from Plassmeyer's quarry three miles east of Westphalia. Tests show a low coefficient of wear, 3.9; good cementing value, 43.6; hardness of 9.0, which is soft; and a low resistance to impact, 8.5.

PERRY COUNTY.

There is an abundance of limestone in this county but in most localities it is covered by clay which is from 2 to 15 feet thick, and it has not been extensively used for road building. Creek gravel is plentiful in all of the streams and has been used to a limited extent on the roads.

Sample 224, blue limestone with a very fine grained texture with occasional streaks and crystals of calcite imbedded, has a smooth sharp concoidal fracture, flinty and somewhat brittle, and has clay disseminated throughout. This sample was taken from hillside about 100 yards southwest of residence of Mr. J. F. DeLassus, near Crosstown. Tests show a medium coefficient of wear, 11.4; good cementing value, 32.0; medium hardness, 15.1; and a low resistance to impact, 8.0.

Sample 225, creek gravel from Dry Fork Creek two miles west of Crosstown on the property of John Eichhorn; consists chiefly of fragments and pebbles of cherty dolomite, free from sand; and has a cementing value of 23.2.

PETTIS COUNTY.

Sample 89, lead colored clayey limestone with open texture and sharp fracture; from a quarry two miles north of Sedalia, owned by D. A. Smith. The quarry has an exposed face of about twenty feet.

grading from a flinty blue limestone at the bottom to a yellowish stone at the top not quite so hard. Tests show a medium coefficient of wear, 10.5; very good cementing value, 88.4; hardness of 8.8; and a low resistance to impact, 10.0.

Sample 90, bank gravel, found on top of limestone ledge from which sample 89 was taken, the gravel bed is about four feet thick at this place. It is found in scattering deposits all over the county. It is composed of fragments of chert partially disintegrated and ranging in size from four inches in diameter to fine sand, colored by iron oxide, and mixed with a very sticky red clay. Tests showed an excellent cementing value, 131.6.

Sample 91, grayish blue limestone having a close dense texture, sharp fracture, and free from clay; from a quarry three and one half miles north of Sedalia, owned by Luther Reed. A twelve foot face is exposed in the quarry. This is known as the Burlington limestone. Tests show a low coefficient of wear, 6.1; good cementing value, 40.6; hardness of 11.6; and a low resistance to impact, 10.0.

Sample 92, creek gravel from Spring Creek near Valda on the Warsaw branch of the Missouri Pacific Railroad; it consists almost entirely of pebbles and fragments of chert mixed with a little sand. The pebbles are smooth and hard except parts of the outside which are disintegrated somewhat. Test showed a good cementing value, 33.4.

PHELPS COUNTY.

The road materials found in this county are pitted dolomite and "cotton rock" of the Jefferson City formation, which occur plentifully in the west half of the county and have been used for road building; and creek gravel which is found in all streams throughout the county.

Sample 158, pitted dolomite, a crystalline magnesian limestone of medium close texture and containing pits filled with clay; from a quarry one mile southwest of Rolla owned by Mrs. M. Hoover. Tests show a low coefficient of wear, 6.6; a fair cementing value, 15.8; hardness of 12.7; which is soft; and a low resistance to impact, 12.5.

Sample 161, "cotton rock" a fine grained magnesian limestone with open texture and containing considerable clay disseminated throughout; from same quarry as sample 158, in ledges immediately over it. Tests show a low coefficient of wear, 7.0; a good cementing value, 59.6; hardness of 12.5; and a low resistance to impact, 10.0.

Sample 160, creek gravel from Beaver creek four miles southwest of Rolla on the farm of Edward Pausel; consisted of chert, dolomite, sand and clay; and showed a cementing value of 23.8.

Sample 159, brownish red sandstone from a quarry four miles

southwest of Rolla on the farm of Edward Pausel. Tests show extremely low coefficient of wear, 0.9; a fair cementing value, 16.0; very soft, 6.3; and a very low resistance to impact, 3.0. This was not considered as a road building material and the tests are given for comparison only.

PIKE COUNTY.

Sample 60, limestone from a quarry on the property of Walter Sanderson in the northeast part of Bowling Green. The city operates a crusher at this quarry and the stone is used on the streets and for concrete construction. A face of about fifteen feet is exposed in the quarry. The tests show a low coefficient of wear, 64; a fair cementing quality, 20.8; hardness of 12.2; and a low resistance to impact, 8.0.

Sample 61, white limestone of rather coarse texture, containing a few fossils; from the quarry of Wall Goodman and Co., at Louisiana. Crushed rock from this quarry is being used on the streets of Louisiana. There is an inexhaustible supply of this rock along the bluffs of the Mississippi River. The sample was crushed in the quarry and the pieces were so small that 83 of them were used in the abrasion test and the pieces were considerable abraded by shipping. Tests show a medium coefficient of wear, 12.9; fair cementing quality, 23.4; medium hardness, 15.1 and a low resistance to impact, 9.0.

PLATTE COUNTY.

Sample 13, brown limestone with coarse open texture, containing clay and sand; from an outcrop on the C. B. & Q. R. R. south of Weston, where a ledge of about four feet is exposed. This sample was very much decomposed, due to weathering. Tests show a low coefficient of wear, 6.9; good cementing value, 26.2; hardness of 9.9; and a low resistance to impact, 5.0.

POLK COUNTY.

Sample 133, fine grained limestone (dolomite) containing a little clay along the stratification planes, also some chert; obtained from the property of J. Johnson three miles east of Bolivar on the Buffalo road, on the east side of Piper Creek. This stone is found in the entire eastern half of the county. Tests show a low coefficient of wear, 5.6; good cementing value, 33.4; hardness of 11.3; and a low resistance to impact, 7.0.

Sample 134, brownish colored limestone (dolomite), very porous and having numerous stratification planes, between which were thin films of clay causing it to separate easily along these planes; obtained from the property of Mrs. Dizzer, four miles southwest of Bolivar, at roadside near Bear Creek. Tests show a low co-

efficient of wear, 4.8; good cementing value, 69.2; hardness of 4.5, which is soft; and a low resistance to impact, 10.

Creek gravel is found in all the streams of the county; and there is also some surface flint rock similar to that in Greene county; this is probably more abundant in the eastern part of the county.

PULASKI COUNTY.

The only samples of road material received from this county were surface outcrop of chert, and limestone; but there is probably an abundant supply of gravel in the Gasconade River and its tributaries.

Sample 228, outcrop chert, nodular in structure, honeycombed on the outer edge, and containing numerous pockets of red iron oxide and quartz; sent in by F. A. Muth from Richland. It appears in outcrops on the surface very abundantly. Tests show medium coefficient of wear, 9.1; good cementing value, 45.6; hardness of 10.7; and a resistance to impact of 12.5, which is just below medium.

Sample 229, magnesian limestone, has a rather open texture, irregular rough fracture, and numerous stratification planes in which is a very thin layer of fine sand and clay; sent in by F. A. Muth from the Frank Godfrey quarry on the property of the Frisco R. R. Co., one half mile southeast of Richland. Tests show a low coefficient of wear, 4.7; good cementing value, 35.0; hardness of 13.2; and low resistance to impact, 9.5.

PUTNAM COUNTY.

Sample 45, limestone, coarse grained and containing many fossils; taken from a 28 inch ledge on the property of the Black Bird Coal Co., Sec. 19, T. 66, R. 18, near Unionville. No quarry exists here and this is said to be about the only stone ledge found in the county. The tests show a medium coefficient of wear, 8.5; a fair cementing quality, 24.0; hardness of 11.3; and a low resistance to impact, 9.0.

RALLS COUNTY.

Limestone is plentiful in this county and gravel occurs in all the stream beds in great abundance and has been largely used on the roads.

Sample 57, blue limestone with rather open texture and containing deposits of pyrite; from the R. H. Caldwell quarry one mile east of New London. The ledge is thirty feet thick. Tests show a medium coefficient of wear, 9.3; a fair cementing value, 23.6; medium hardness, 14.6; and a low resistance to impact, 10.0.

Sample 58, creek gravel from Salt River two miles east of New London; consists of chert, limestone, a few pebbles of quartz, and about 45% of sand. The pebbles are very hard and smooth and

range in size from 1½ inches to fine sand. Test shows excellent cementing properties, 138, and indicates a good road metal.

Sample 59, white limestone having a coarse granular structure and containing streaks of clay and sandstone; from a quarry three miles north of New London owned by Reglus Watkins. The ledge is twenty feet thick. Tests show a low coefficient of wear, 5.6; good cementing value, 25.2; hardness of 9.8; and a low resistance to impact, 8.0.

RAY COUNTY.

Sample 5, dark blue limestone, known as "mine rock" as it occurs above a three foot vein of coal; obtained from the dump of the Pea Ridge Stone Co. at Richmond, owned by T. J. Graham. Tests show a low coefficient of wear, 6.3; good cementing value, 60.8; medium hardness, 15.3; and low resistance to impact, 10.0.

Sample 6, clayey limestone with a rought nodular structure, containing a few fossils, having a rough fracture and very close fine texture; obtained from a quarry on the farm of C. R. Kirkham one mile north of Orrick. It occurs in ledges about 8 feet thick and outcrops in the hills throughout the southwest portion of the county. Tests show a low coefficient of wear, 6.9; excellent cementing value, 154.6; medium hardness, 14.2; and a low resistance to impact, 6.0.

Sample 7, gray limestone with dense texture and very rough fracture, having streaks of calcite and many fossils imbedded; from the farm of C. R. Kirkham, one mile north of Orrick. It outcrops in ledges from 3 to 8 inches in thickness and is found in the southwest and north parts of the county. Tests show a low coefficient of wear, 6.6; good cementing value, 74.8; hardness of 11.1; and a medium resistance to impact, 14.0.

REYNOLDS COUNTY.

The road materials found in this county are limestone, which is plentiful in the hills along Black River; and an abundance of creek gravel; but neither of these has been used on the roads.

Sample 174, magnesian limestone with close crystalline texture, contains pits filled with sand and has considerable sand disseminated throughout; taken from bluffs on west side of Black River on the farm of C. C. Odell about one quarter of a mile east of Centerville. Tests show a low coefficient of wear, 4.5; good cementing value, 37.6; hardness of 9.8, which is low; and a low resistance to impact, 12.5.

Sample 175, gravel from Black River one quarter of a mile northeast of Centerville on the farm of J. H. Parks; consists chiefly of chert, cherty dolomite, and quartzite, very clean and free from sand. It has a cementing value of 26.6.

RIPLEY COUNTY.

Road materials collected from this county are limestone, which occurs plentifully over the county; chert or flint rock occurs plentifully (except in the "Flat Woods" or swampy district) both as large boulders and as finely disintegrated material; creek gravel occurs in Current River in large quantities; and white sandstone (quartzite) occurs in large quantities in various localities.

Sample 183, dark gray limestone, fine crystalline texture, rough fracture, containing small pits filled with sand and red iron oxide; from cut on Iron Mountain R. R. two miles east of Doniphan. Tests show high coefficient of wear, 17.3; good cementing value, 40.0; medium hardness 16.1, and medium resistance to impact, 14.0. These tests are high for limestone.

Sample 184, chert, colored red by oxide of iron, very brittle, breaking in small fragments under light blows of the hammer; taken from R. R. cut two miles east of Doniphan. Tests show low coefficient of wear, 7.1; good cementing value, 52.6; hardness of 11.6, which is soft; and low resistance to impact, 9.0.

Sample 185, gravel from Current River 200 yards below wagon bridge at Doniphan on the farm of T. L. Wright; consists chiefly of chert and quartzite, very hard and free from sand; and has a fair cementing value, 20.2.

Sample 186, white sandstone, quartzite, taken from the hillside one quarter of a mile northwest of Doniphan on the farm of H. O. Maness. Tests show medium coefficient of wear, 10.5; good cementing value, 29.8; medium hardness, 15.7; and medium resistance to impact, 16.5.

ST. CLAIR COUNTY.

Sample 135, dark gray limestone with coarse texture and rough fracture, containing crystals of calcite; from Hallowell's lime kiln three quarters of a mile northwest of Osceola. Tests show low coefficient of wear, 4.8; good cementing value, 36.2; hardness of 12.7; and a very low resistance to impact, 6.0.

Dolomite is found in the eastern part of the county, but no sample of this was obtained.

Sample 136, creek gravel from the Osage River at Osceola; consisting of small pebbles and fragments of chert mixed with about 30% of earth, the pebbles are very hard and smooth. Test showed a good cementing value, 50.6.

ST. FRANCOIS COUNTY.

Road material is very plentiful in this county and there is a great variety. Granite is plentiful in the vicinity of Knob Lick; creek gravel occurs plentifully in all the streams; "chats" and waste

limestone from the mines, which have been the principal road materials used; and porphyry is plentiful in the west part of the county.

Sample 203, red granite with coarse interlocking crystals, from the Gilsonite Granite Co.'s quarry one mile west of Knob Lick; used mostly for paving blocks. Tests show a high coefficient of wear, 16.0; good cementing value, 39.0; hardness 19.0; and a high resistance to impact, 25.5.

Sample 204, gray granite with large interlocking crystals, rough fracture and very hard; from quarry three quarters of a mile west of Knob Lick, owned by Edward Price; used mostly for paving blocks. Tests show very high coefficient of wear, 21.0; fair cementing value, 23.0; hardness of 18.9; and a medium resistance to impact, 17.0.

Sample 205, blue granite with large interlocking crystals, from a quarry one half mile west of Knob Lick owned by Edward Price; used some for dimension stone work. Tests show a medium coefficient of wear, 9.5; a fair cementing value, 21.8; hardness of 12.8, which is soft; and a medium resistance to impact, 16.5.

Sample 206, creek gravel from St. Francois River three miles southwest of Farmington; consists chiefly of chert, quartz and sand; and has a fair cementing value, 11.0.

Sample 207, "chats" from the Doe Run Lead Co.'s mine at Doe Run, near Farmington; it is crushed very fine and has a fair cementing value, 20.8.

Sample 208, mineral bearing limestone, waste from the Doe Run Lead Co.'s mine near Farmington. Tests show a medium coefficient of wear 8.9; a fair cementing value, 21.6; hardness of 10.1, which is soft; and a medium resistance to impact, 13.5.

Sample 209, blue limestone of close texture, containing crystals of calcite, rough fracture; from quarry one quarter of a mile northeast of Court House in Farmington, owned by Alex. Moore; used for road and building purposes. Tests show a medium coefficient of wear, 8.5; good cementing value, 30.6; hardness 13.6; and medium resistance to impact, 15.0. These tests are rather high for limestone.

Sample 211, porphyry, "trap", dark colored, close texture, and rough fracture; from a hill one half mile northwest of Bismark, owned by Fred Driemeyer. Tests show a high coefficient of wear, 14.8; very good cementing value, 89.0; hardness of 19.7; and a medium resistance to impact, 15.0. These tests indicate a good road metal.

STE. GENEVIEVE COUNTY.

The road materials found in this county are limestone, which is plentiful along the bluffs rising on the west side of the Mississippi River bottoms and is being used on the roads; and the streams of

the county afford an abundant supply of gravel which has not been used extensively in road building.

Sample 221, white limestone with a uniform crystalline texture, sharp rough fracture, contains numerous stratification planes, and is easily broken onto polygonal blocks; from a quarry two and one half miles southeast of Ste. Genevieve, owned by Clay Siegel. Tests show a medium coefficient of wear, 10.5; good cementing value, 28.6; hardness of 9.9; and a low resistance to impact, 6.0.

Sample 222, creek gravel taken from creek in Ste. Genevieve, five blocks southwest of Frisco depot, near iron bridge, on the property of Conrad Millheiser; it consists of chert and sand; and has a good cementing value, 56.6.

Sample 230, gray limestone, crystalline, with a foliated structure, containing a few fossils and a little sand and clay along the stratification planes; from quarry in Ste. Genevieve owned by William Baumsbark. Tests show a low coefficient of wear, 6.3; good cementing value, 32.8; hardness of 13.7; and low resistance to impact, 12.5.

ST. LOUIS COUNTY.

There is an abundance of limestone for road building in this county and a great many macadam roads have been built of this material; disintegrated chert, known as "silica", is found in the northwestern part of the county; and creek gravel is found in the small streams; for a test on Meramec River gravel see report on Dent County.

Sample 74, blue limestone, from the Sinclair quarry on the estate of George Penn, Jr. at Vigus. Tests show a medium coefficient of wear, 9.3; good cementing value, 53.2; medium hardness, 13.7; and a medium resistance to impact, 15.5. These tests are above the average for limestone. Four other small samples of limestone from four different quarries in St. Louis county had previously been tested in the laboratory and showed a coefficient of wear of 9.3.

Sample 231, disintegrated chert, known as "silica", sent in by J. W. Shields from Centaur Station; it is white in color and very brittle and has a good cementing value, 36.6. This material would probably form a good binder for gravel or other hard road material.

Sample 232, creek gravel, sent in by J. W. Shields from Centaur Station; consists chiefly of pebbles and fragments of very hard chert; and has a fair cementing value, 17.6.

SALINE COUNTY.

This county has comparatively little road material except along Black Water River in the southern part. Two miles northeast of Marshall there is gravel in very limited quantities and limestone is also found in the vicinity of Slater.

Sample 80, gray limestone with a coarse crystalline texture, good

fracture and easily broken into rectangular pieces; from Kockmeyer's quarry at Naptonville. Tests show a medium coefficient of wear, 8.2; good cementing value, 45.6; hardness of 9.0; and a low resistance to impact, 5.0.

SCHUYLER COUNTY.

There are no quarries in this county and no ledges exist where quarries could be developed; drift rock, or "nigger heads" exist abundantly all over the county and according to the County Highway Engineer sample 46 is an average of the existing stone.

Sample 46, glacial drift rock consisting of boulders, from four to six inches in diameter, of limestone, red granite, greenstone, sandstone, and quartzite; the feldspars were badly decomposed. These were field stones picked up near Lancaster. The boulders were broken and mixed together and subjected to the abrasion and cementation tests; but the other tests were not made owing to the variety of rocks. The tests show a low coefficient of wear, 5.9; and a good cementing value, 70.6.

SCOTT COUNTY.

The road materials found in this county are "hill gravel" which is plentiful in the north part of the county and has been used considerably on the roads; limestone is not widely distributed but occurs in considerable quantities in the hills of the north part of the county; and distintegrated chert or flint, known as "silica", occurs in large quantities and has been used by the Frisco R. R. for ballast.

Sample 187, "hill gravel", from gravel pit one mile west of Benton on the farm of Mrs. Mary Glastutter; it consists chiefly of pebbles and fragments of very hard chert and has a good cementing value, 38.0.

Sample 188, dark gray crystalline limestone, medium close texture and rough fracture, containing numerous large crystals of calcite; taken from hillside near Ray's Landing on the Frisco R. R. three miles north of Commerce, on the farm of Herman Muach. Tests show a medium coefficient of wear, 8.9; good cementing value, 60.2; hardness of 13.3; and very low resistance to impact, 5.0.

Sample 189, disintegrated chert or flint, known as "silica," has a very fine dense texture, chalky white in color, and easily broken into fragments; taken from R. R. cut about two miles north of Commerce. Tests show a low coefficient of wear, 6.3; good cementing quality, 42.4; hardness 9.9; and a low resistance to impact, 10.0.

SHANNON COUNTY.

The road materials found in this county are rhyolite, which occurs in large quantities in several localities in the eastern part of the county; limestone which is plentiful all over the county; creek gravel is plentiful in stream beds; and surface stones of chert and

flint similar to samples 75 and 76 from Howell county.

Sample 167, rhyolite or porphyry, from the Roger's Copper mine one and three quarter miles east of Emminence on the property of the Michigan Cattle Co. Tests show a medium coefficient of wear, 10.0; good cementing quality, 50.0; hardness of 18.6, which is high; and a high resistance to impact, 23.5. These tests indicate a fine road material.

Sample 168, magnesian limestone, from quarry one half mile east of Emminence owned by H. A. Hennon. Tests show a low coefficient of wear, 6.2; good cementing qualities, 40.0; hardness of 10.3, which is soft; and a low resistance to impact, 11.5.

Sample 169, creek gravel, taken from Jack's Fork of Current River one half mile east of Emminence on the farm of Andrew Hawkins; consists chiefly of chert and quartz mixed with sand; and has a fair cementing value, 16.8.

STODDARD COUNTY.

The only road material found in this county is creek gravel, a sample of which was sent in by Mr. O. L. Pulsee, Highway Engineer of Stoddard county.

Sample 233, creek gravel, from the farm of J. W. Covington near Bloomfield; consisting chiefly of pebbles of chert, quartzite, quartz and sand. It has a good cementing value, 30.0.

STONE COUNTY.

Sample 118, white magnesian limestone, fine grained, open texture, uniform structure; from the railroad cut just north of station at Galena. This deposit is of great depth, extending down to the James River one hundred feet or more and as much above. Tests show a low coefficient of wear, 4.8; good cementing value, 44.0; hardness of 6.3, which is soft; and a low resistance to impact, 5.0.

Sample 119, surface flint rock, badly weathered and honeycombed and cracked in many places. The color on the interior was a grayish blue white, the outside is colored red with iron oxide. From the property of Bud Standard, one mile north of Galena, on the road to Clark's Inn. The hills in this locality are all covered with this material left by the disintegration of the surrounding limestone. It is also found mixed with the clay below the surface. The tests show a low coefficient of wear, 7.4; good cementing value, 28.2; medium hardness, 14.6; and a low resistance to impact, 7.0.

Sample 120, blue limestone with close dense texture, sharp smooth fracture, and having streaks of clay running through it; from the property of Bud Standard, one mile north of Galena, on the road to Clark's Inn, near the top of the hills. Tests show medium coefficient of wear, 8.5; good cementing value, 33.6; hardness of 13.3; and a low resistance to impact, 5.0.

There is an abundance of gravel in James River and other streams and "hill gravel" similar to that found in Jasper county occurs in great quantities.

SULLIVAN COUNTY.

The only available stone for road purposes in this county is limestone, two samples of which were received.

Sample 43, shaley limestone containing a large percentage of sand, the bedding planes are very close together and it separates easily along them; taken from between two ledges of sandstone on the highway one mile north of Milan, near the property of A. D. Payne. Tests show very low coefficient of wear, 4.0; very excellent cementing qualities 239.6; hardness of 7.0; and low resistance to impact, 9.0. This stone is too soft even for light traffic, but might be used as a binder for harder material with good results.

Sample 44, limestone with a coarse open texture, from an old quarry one half mile south of Milan, owned and operated by Hiram Grear. Tests show medium coefficient of wear, 8.5; fair cementing value, 20.6; hardness of 12.4; and a medium resistance to impact, 13.5.

TEXAS COUNTY.

The road materials received from this county are magnesian limestone or "cotton rock", which is said to be plentiful over the county; "hill gravel," occuring in beds from two to fifteen feet deep on the hillsides all over the county; and creek grävel. Samples of all these were obtained near Cabool.

Sample 162, magnesian limestone, from a quarry one quarter of a mile east of Cabool on land owned by J. L. Neff, has a close texture, smooth fracture, and is easily broken into rectangular pieces. Tests show a low coefficient of wear, 7.8; a good cementing value, 30.4; a hardness of 12.3, which is soft, and a low resistance to impact, 10.0.

Sample 163, creek gravel, from creek one quarter of a mile east of Cabool; consists of pebbles of very hard chert, and has a low cementing value, 8.6.

Sample 164, "hill gravel," taken from hillside two and one half miles west of Cabool on the farm of Grant and Davis, consists of fragments of chert mixed with clay; it is very hard and has a fair cementing value, 14.4. It is said that in many localities excellent natural road surfaces of this material exist.

VERNON COUNTY.

Road materials in this county are not plentiful; there is little limestone except in the scattered knolls in the northern and western parts. South and east of Nevada the formation is mostly sandstone.

Sample 105, blue limestone with a close dense texture and sharp fracture, containing streaks of calcite disseminated throughout; taken from the top of a large knoll on the farm of Mrs. Fairchild one half mile north of Eve. Tests show a low coefficient of wear, 6.8; good cementing value, 26.4; medium hardness, 16.0; and a low resistance to impact, 6.0.

Sample 106, brown limestone with medium close texture and containing a large percentage of clay disseminated throughout; taken from the same knoll as sample 105; it exists about twenty feet below 105 in a very shattered formation. The tests show a low coefficient of wear, 7.4; a fair cementing value, 24.0; hardness of 6.2; and a low resistance to impact, 9.0.

Sample 107, black limestone, or siderite, very dense and has a sharp fracture; taken from an outcrop at the base of the knoll from which samples 105 and 106 were taken and was covered with red iron oxide. The ledge is not over two feet thick and overlies a bed of coal. Tests show a high coefficient of wear, 13.3; good cementing value, 49.0; medium hardness, 16.9; and a medium resistance to impact, 14.0.

106 and 107 are not found east of Eve; but are plentiful westward to Fort Scott, Kansas, over a strip about two miles wide.

WASHINGTON COUNTY.

Limestone is plentiful all over the county but has not been used much on the roads. Creek gravel is plentiful in the streams and has been used to some extent for surfacing the roads.

Sample 217, silicious limestone, close crystalline texture, the cementing material being silica, has a rough fracture and shows green oxide of copper; from a quarry two miles west of Potosi on property of Lincoln Trust Co. Tests show a low coefficient of wear, 5.4; good cementing value, 40.4; hardness of 13.6; and low resistance to impact, 10.0.

Sample 218, creek gravel from bed of creek one hundred yards south of court house at Potosi on the property of Perry Bass; consists of chert and cherty dolomite mixed with sand and earth; and has low cementing value, 9.0.

WAYNE COUNTY.

The road materials of this county are two granite quarries north of Piedmont where there is a large quantity of spalls that could be crushed for macadam; limestone in the western part of the county in large quantities; and creek gravel is plentiful over the county. Very few macadamized roads have been built.

Sample 177, dark gray granite, from old quarry one and one half miles northeast of Piedmont owned by J. H. Kelly. Tests show a very high coefficient of wear, 22.1; a good cementing value, 69.4;

hardness of 17.9; and a high resistance to impact, 28.0; which indicate an excellent road material.

Sample 178, magnesian limestone, dark gray in color and containing pits filled with sand and red oxide; from a quarry one quarter of a mile north of Piedmont owned by S. A. Bates. Tests show a low coefficient of wear, 5.3; a good cementing value, 26.0; hardness of 10.4, which is soft; and a low resistance to impact, 12.0.

Sample 179, creek gravel, from the bed of McKenzie creek one half mile northeast of Piedmont on the farm of John Jordan; consists of chert, quartzite and andesite, free from earth and sand; and has a fair cementing value, 15.6.

WEBSTER COUNTY.

Sample 129, white limestone (dolomite), fine grained but rather open texture. It is easily broken into rectangular pieces and has a little clay between the stratification planes. Obtained from a quarry four miles northeast of Marshfield on the property of Mrs. Whittaker. It is found throughout the north half of the county and along James River. Tests show a low coefficient of wear, 5.1; good cementing value, 60.4; very soft, 0.0; and a low resistance to impact, 6.0. These tests indicate a poor road metal.

Sample 130, cherty dolomite, known as flint rock, containing pockets of sand, badly pitted and honeycombed and the outer edges were badly disintegrated, being of a chalky nature and colored with iron oxide; taken from the property of Mrs. Whittaker four miles northeast of Marshfield. It occurs in large quantities all over the county as surface or field stones. Tests show a very low coefficient of wear, 3.9; good cementing value, 74.6; medium hardness, 14.4; and medium resistance to impact, 17.0.

Gravel is found in all the streams in this county, but no samples were obtained.

WORTH COUNTY.

Sample 25, limestone from an old quarry on the farm of O. P. M. Mills six miles east of Grant City, on Grand River; the ledge is three and one half feet thick. This is about the only kind of rock found in the county and it has not been used to any extent on the roads. The tests show a very high coefficient of wear, 25.0; good cementing quality, 74.0; hardness of 8.5; and a low resistance to impact, 9.0. This very high coefficient of wear should be regarded as doubtful until confirmed by another test, as the test for hardness does not indicate such wearing quality.

TABULATION OF RESULTS.

NUMBER.	NAME.	COUNTY.	Percent of Wear	French coeff. of Wear.	Cementing Value.	Hardness	Toughness	Specific Gravity	Weight per cu. ft.—solid form	Water absorbed in lbs. per cu. ft.
1	Sandstone	Carroll	14.2	2.8	51.6	5.5	7	2.28	142.5	7.13
2	Limestone	Carroll	4.3	9.3	26.6	12.9	10	2.67	166.9	1.50
3	Limestone	Carroll	5.7	7.0	14.0	10.6	7	2.69	168.1	0.67
4	Limestone	Carroll	3.1	12.9	115.8	14.2	16	2.60	168.1	0.39
5	Limestone	Ray	6.3	6.3	60.8	15.3	10	2.62	163.8	2.81
6	Limestone	Ray	5.8	6.9	154.6	14.2	6	2.62	163.8	0.29
7	Limestone	Ray	6.0	6.6	74.8	11.1	14	2.66	165.3	0.03
8	Limestone	Clay	2.9	13.8	22.2	14.7	10	2.72	170.0	1.02
9	Limestone	Clay	4.1	9.7	14.2	13.8	8	2.62	163.8	2.45
10	Limestone	Clay	5.3	7.5	14.2	11.4	6	2.69	168.1	1.37
11	Limestone	Clay	5.7	7.0	27.0	14.1	6	2.66	165.3	1.49
12	Limestone	Clay	5.0	8.0	56.4	16.2	12	2.63	164.3	2.02
13	Limestone	Platte	5.8	6.9	2.62	9.9	5	2.51	156.9	7.82
14	Limestone	Clinton	4.7	9.5	43.2	12.5	8	2.63	164.3	0.86
15	Limestone	Clinton	3.4	11.8	61.0	12.5	7	2.63	164.3	0.59
16	Limestone	Buchanan	3.9	10.2	48.6	13.4	7	2.71	169.4	0.76
17	Limestone	Buchanan	5.2	7.7	32.2	13.8	5	2.68	167.5	0.51
18	Limestone	Andrew	6.0	5.8	19.0	9.4	6	2.63	164.4	0.94
19	Limestone	Andrew	6.4	6.2	30.6	9.4	10	2.60	162.5	2.93
20	Limestone	Andrew	10.7	3.7	23.2	5.6	6	2.43	151.9	6.23
21	Limestone	Holt	5.6	7.1	103.8	9.8	7	2.63	164.4	1.17
22	Limestone	Holt	5.4	7.6	51.4	11.4	13	2.62	163.8	1.80
23	Limestone	Harrison	6.8	5.9	112.6	10.2	9	2.45	153.1	1.96
24	Limestone	Hanison	5.8	6.9	33.8	16.8	13	2.40	150.0	10.40
25	Limestone	Worth	1.6	25.0	74.0	8.5	9	2.69	168.0	1.96
26	Limestone	Gentry	6.7	5.9	105.8	8.2	10	2.68	167.5	1.51
27	Limestone	Gentry	3.3	12.1	54.6	12.7	14.5	2.45	153.1	5.21
28	Limestone	Gentry	4.4	9.0	32.6	14.1	7.0	2.65	165.6	1.33
29	Limestone	Daviess	4.1	9.7	17.0	13.8	14.5	2.65	165.6	2.50
30	Limestone	Daviess	4.6	8.7	38.6	13.4	11	2.69	168.0	1.21
31	Limestone	Daviess	4.5	8.8	19.6	14.7	8	2.64	165.1	0.84
32	Limestone	Mercer	4.4	9.1	41.2	13.2	7	2.64	165.1	2.44
33	Limestone	Mercer	4.6	8.7	38.0	11.8	8	2.67	166.9	0.68

34	Limestone	Grundy	6.5	6.1	26.8	6.7	6	2.64	165.1	2.64
35	Limestone	Dekalb	3.4	11.7	16.6	14.3	10	2.65	165.8	2.65
36	Limestone	Dekalb	4.5	8.8	14.8	11.3	8	2.66	165.3	0.21
37	Limestone	Dekalb	5.0	8.0	11.6	10.2	7	2.79	174.2	3.22
38	Limestone	Caldwell	6.5	6.1	35.0	12.3	7	2.51	156.9	2.65
39	Limestone	Caldwell	8.5	4.7	29.2	8.3	9	2.62	163.8	2.94
40	Limestone	Caldwell	46.2	0.8	9.0	3.4	7	2.15	134.5	5.18
41	Limestone	Linn	3.6	11.1	38.8	14.6	11	2.68	167.5	0.54
42	Limestone	Linn	6.8	5.9	13.2	8.5	9	2.65	165.6	1.41
43	Limestone	Sullivan	9.9	4.0	239.6	7.0	9	2.56	160.0	3.04
44	Limestone	Sullivan	4.7	8.5	20.6	12.4	13.5	2.59	161.9	4.40
45	Limestone	Putnam	4.7	8.5	24.0	11.3	9.0	2.70	168.8	2.36
46	Glacial Drift	Schuyler	6.8	5.9	70.6	...	...	...	....	....
47	Limestone	Clark	2.9	13.8	51.0	10.8	8.0	2.59	161.9	0.84
48	Limestone	Clark	4.6	8.7	69.8	14.3	5.0	2.78	173.8	0.96
49	Limestone	Clark	4.3	9.3	50.8	12.7	14.0	2.59	161.9	2.59
50	Limestone	Lewis	5.9	6.8	31.4	8.4	11.5	2.64	165.1	2.81
51	Limestone	Knox	8.4	4.8	55.8	8.5	11.0	2.59	161.9	1.78
52	Limestone	Knox	6.3	6.3	33.4	12.9	7.0	2.73	170.6	0.12
53	Limestone	Macon	4.2	9.5	34.8	11.7	8.0	2.70	168.8	0.79
54	Limestone	Marion	6.9	5.8	87.4	9.6	10.0	2.58	161.3	1.97
55	River Gravel	Marion	...	...	14.8	...	...	...	....	....
56	Limestone	Marion	8.6	4.6	28.2	12.6	12.5	2.68	167.7	1.93
57	Limestone	Ralls	4.3	9.3	23.6	14.6	10.0	2.56	160.0	3.08
58	River Gravel	Ralls	...	...	138.0	...	...	...	....	....
59	Limestone	Ralls	7.2	5.6	25.2	9.8	8.0	2.68	167.7	2.61
60	Limestone	Pike	6.2	6.4	20.8	12.2	8.0	2.62	163.8	3.20
61	Limestone	Pike	3.1	12.9	23.4	15.1	9.0	2.64	165.2	2.82
62	Limestone	Lincoln	3.1	12.9	107.0	13.5	11.0	2.71	169.2	1.61
63	Limestone	Lincoln	5.1	7.9	52.0	11.4	10.0	2.70	168.8	3.04
64	Limestone	Chariton	3.2	12.8	28.2	10.3	11.0	2.64	165.1	0.35
65	Sandstone	Chariton	25.0	1.6	21.0	3.4	5.0	2.22	138.8	11.10
66	Limestone	Monroe	8.6	4.7	138.8	3.5	4.0	2.52	157.5	1.80
67	Limestone	Monroe	7.9	5.1	37.2	5.1	7.0	2.56	160.0	6.65
68	River Gravel	Monroe	...	...	39.0	...	...	...	....	....
69	Limestone	Boone	7.4	5.4	132.4	10.1	7.0	2.63	164.4	1.18
70	Limestone	Boone	11.3	3.5	42.6	13.3	9.0	2.65	165.8	2.58
71	Sandstone	Livingston	18.8	2.1	139.4	0.0	4.0	2.12	132.5	10.30
72	Limestone	Livingston	4.1	9.7	93.4	13.8	8.0	2.65	165.6	1.08
73	Limestone	Daviess	5.0	8.0	64.0	10.7	14.0	2.68	167.5	1.37
74	Limestone	St. Louis	4.3	9.3	53.2	13.7	15.5	2.68	167.5	0.25
75	Chert	Howell	6.7	5.9	206.8	10.2	9.0	2.56	160.0	1.79
76	Feldstone (chert)	Howell	8.2	4.9	277.4	9.6	7.5	2.36	147.5	5.02
77	Hard-pan Gravel	Marion	...	...	180.8	...	...	...	....	....
78	Limestone	Cooper	4.9	8.2	25.2	8.6	6.0	2.65	165.6	0.09

TABULATION OF RESULTS.

NUMBER.	NAME.	COUNTY.	Percent of Wear	French coeff. of Wear.	Cementing Value.	Hardness	Toughness	Specific Gravity	Weight per cu. ft. —solid form	Water absorbed in lbs. per cu. ft.
79	Limestone	Cooper	12.1	3.3	92.2	7.6	5.0	2.63	164.4	0.81
80	Limestone	Saline	4.9	8.2	45.6	9.0	5.0	2.61	163.1	1.15
81	Limestone	Lafayette	8.4	4.8	71.4	8.9	6.0	2.65	165.6	1.24
82	Limestone	Lafayette	4.4	9.1	51.4	13.7	7.0	2.67	166.9	3.00
83	Limestone	Jackson	6.9	5.8	65.5	9.9	8.0	2.59	161.9	2.43
84	Limestone	Jackson	5.5	7.3	25.4	13.8	6.0	2.57	160.6	2.60
85	Limestone	Jackson	5.1	7.8	107.8	14.5	9.5	2.65	165.6	1.57
86	Limestone	Jackson	5.9	6.7	27.0	6.8	4.0	2.67	166.9	1.17
87	Limestone	Cass	6.2	6.4	43.8	13.7	6.0	2.60	162.5	1.92
88	Limestone	Johnson	4.7	8.5	36.4	15.8	13.0	2.66	166.5	1.33
89	Limestone	Pettis	3.8	10.5	88.4	8.8	10.0	2.64	162.9	4.56
90	Gravel	Pettis	...	...	131.6	...	...	...	....	....
91	Limestone	Pettis	6.6	6.1	40.6	11.2	7.0	2.63	164.4	0.16
92	Creek Gravel	Pettis	...	...	33.4	...	...	...	....	....
93	Creek Gravel	Moniteau	...	...	61.2	...	...	...	....	....
94	Dolomite	Cole	4.9	8.2	24.6	4.7	4.0	2.58	161.3	5.65
95	Creek Gravel	Cole	...	...	42.6	...	...	...	....	....
96	Hard-pan Gravel	Miller	...	...	317.0	...	...	...	....	....
97	River Gravel	Miller	...	...	16.4	...	...	...	....	....
98	Dolomite	Miller	5.4	7.4	29.4	4.1	5.0	2.39	149.4	6.01
99	Creek Gravel	Morgan	...	...	23.2	...	...	...	....	....
100	Limestone	Benton	7.5	5.3	16.6	9.6	7.0	2.56	160.0	1.63
101	Hard-pan Gravel	Benton	...	...	167.8	...	...	...	....	....
102	Limestone	Cass	5.8	6.9	45.2	9.3	12.0	2.52	158.7	0.21
103	Limestone	Bates	4.0	10.0	26.0	11.7	3.0	2.62	163.8	0.23
104	Limestone	Bates	6.5	6.1	50.4	13.4	11.0	2.67	166.9	0.38
105	Limestone	Vernon	5.9	6.8	26.4	16.0	6.0	2.71	169.3	0.20
106	Limestone	Vernon	5.4	7.4	24.0	6.2	9.0	2.52	158.7	3.33
107	Limestone	Vernon	3.0	13.3	49.0	16.9	14.0	2.88	180.0	0.04
108	Limestone	Cedar	8.2	4.9	16.0	9.8	8.0	2.67	166.9	0.05
109	Limestone	Barton	8.0	5.0	41.0	1.9	6.0	2.58	161.3	1.29
110	Flint	Barton	3.7	10.3	34.4	19.1	11.0	2.46	153.8	4.64

111	Pit Gravel	Jasper	...	...	83.0	...	...	...	....	....
112	Dolomite	Jasper	10.2	3.9	10.0	11.1	15.0	1.82	113.8	3.34
114	Limestone	Jasper	5.9	6.8	41.6	12.1	7.0	2.64	165.0	1.15
115	Limestone	Newton	4.6	8.7	22.8	12.8	12.0	2.67	166.9	0.65
116	Creek Gravel	Newton	...	...	72.0	...	...	...	....	....
117	Dolomite	Newton	14.3	2.8	63.2	12.5	10.0	2.08	130.0	10.27
118	Dolomite	Stone	8.1	4.8	44.0	6.3	5.0	2.71	169.6	5.08
119	Flint	Stone	5.4	7.4	28.2	14.6	7.0	2.31	144.4	6.94
120	Limestone	Stone	4.7	8.5	33.6	13.3	5.0	2.66	165.3	0.43
121	Limestone	Lawrence	11.8	3.4	34.6	10.5	4.0	2.63	164.4	0.33
122	Dolomite	Lawrence	16.8	2.4	37.6	15.8	11.0	1.01	119.4	16.72
123	Creek Gravel	Lawrence	...	...	36.0	...	...	...	....	....
124	Limestone	Dade	6.8	5.8	31.0	7.4	5.0	2.64	162.9	0.49
125	Flint Boulders	Dade	8.4	4.8	12.8	12.3	9.0	2.48	155.0	2.79
126	Limestone	Greene	7.7	5.2	46.2	6.8	5.0	2.66	166.3	1.66
127	Dolomite	Greene	6.7	5.9	12.4	15.5	12.5	2.26	141.3	6.22
128	Creek Gravel	Greene	...	...	25.6	...	...	...	....	....
129	Dolomite	Webster	7.8	5.1	6.04	0.0	6.0	2.50	156.3	3.04
130	Dolomite	Webster	10.1	3.9	74.6	14.4	17.0	2.33	145.6	4.37
131	Dolomite	Laclede	7.9	5.1	51.2	15.5	13.0	2.73	170.6	0.73
132	Creek Gravel	Laclede	...	...	56.0	...	...	...	....	....
133	Dolomite	Polk	7.2	5.6	33.4	11.3	7.0	2.54	158.7	4.86
134	Dolomite	Polk	8.4	4.8	69.2	4.5	10.0	2.35	146.9	8.37
135	Limestone	St. Clair	8.4	4.8	36.2	12.7	6.0	2.65	165.6	2.82
136	River Gravel	St. Clair	...	...	50.6	...	...	...	....	....
137	Limestone	Osage Co	8.9	4.5	28.4	6.7	6.0	2.55	159.4	5.88
138	Creek Gravel	Osage Co	...	...	80.2	...	...	...	....	....
139	Dolomite	Osage Co	10.1	3.9	43.6	9.0	8.5	2.65	165.5	3.81
140	Dolomite	Gasconade	5.9	6.8	58.4	12.7	9.0	2.50	157.3	7.84
142	Limestone	Franklin	4.8	8.3	19.0	12.6	15.5	2.53	157.8	6.41
143	Limestone	Franklin	9.1	4.4	23.6	12.1	10.0	2.66	166.4	4.66
144	Bank Gravel	Franklin	...	...	41.0	...	...	...	....	....
145	Limestone	Gasconade	6.3	6.3	71.2	15.2	13.5	2.58	161.0	8.00
146	Creek Gravel	Gasconade	...	...	36.2	...	...	...	....	....
147	Hill Gravel	Maries	...	...	26.4	...	...	...	....	....
148	Creek Gravel	Maries	...	...	5.8	...	...	...	....	....
149	Limestone	Maries	52.3	0.8	36.0	5.3	6.5	2.62	163.7	6.97
150	Limestone	Dent	4.2	9.5	22.2	11.5	12.0	2.62	163.7	2.43
151	Hill Gravel	Dent	...	...	31.2	...	...	...	....	....
152	Creek Gravel	Dent	...	...	75.8	...	...	...	....	....
154	Limestone	Crawford	11.0	3.6	25.6	1.3	8.0	2.67	167.0	3.34
155	Hill Gravel	Crawford	...	...	12.2	...	...	...	....	....
156	Creek Gravel	Crawford	...	...	44.6	...	...	...	....	....
158	Limestone	Phelps	6.0	6.6	15.8	12.7	12.5	2.72	170.0	4.10

TABULATION OF RESULTS.

NUMBER.	NAME.	COUNTY.	Percent of Wear	French coeff. of Wear.	Cementing Value.	Hardness	Toughness	Specific Gravity	Weight per cu ft. —solid form	Water absorbed in lbs. per cu. ft.
159	Sandstone	Phelps	41.8	0.9	16.0	6.3	3.0	2.32	145.0	10.30
160	Creek Gravel	Phelps	...	...	23.8	...	...	...	....	....
161		Phelps	5.7	7.0	59.6	12.5	10.0	2.60	162.0	6.48
162		Texas	5.1	7.8	30.4	12.7	10.0	2.64	165.0	2.64
163		Texas	...	...	8.6	...	...	...	....	....
164		Texas	...	...	14.4	...	...	...	....	....
165		Howell	...	...	37.2	...	...	...	....	....
166		Howell	47.6	0.8	4.4	4.3	2.0	2.50	157.7	3.21
167	Rhyolite	Shannon	4.0	10.0	50.0	18.6	23.5	2 71	169.5	0.10
168	Limestone	Shannon	6.5	6.2	40.0	10.3	11.5	2 73	170 0	1.02
169	Creek Gravel	Shannon	...	...	16.8	...	...	...	....	....
170	Granite	Carter	2.7	14.8	34.2	19.3	14.0	2.68	167.5	2.18
171	Limestone	Carter	5.4	7.4	19.8	9.7	11.0	2.79	174.5	1.57
172	Creek Gravel	Carter	...	...	17.8	...	...	...	....	....
173	Sandstone	Carter	56.4	0.7	8.6	5.0	4.5	2.32	145.0	5.80
174	Limestone	Reynolds	8.8	4.5	37.6	9.8	12.5	2.82	176.4	1.69
175	Creek Gravel	Reynolds	...	...	26.6	...	...	...	....	....
176	Sandstone	Reynolds	40.2	1.0	5.2	6.1	3.0	2.37	147.0	4.47
177	Granite	Wayne	1.8	22.1	09.4	17.9	28.0	2.72	169.9	0.80
178	Limestone	Wayne	7.6	5.3	26.0	10.4	12.0	2.86	178.7	0.45
179	Creek Gravel	Wayne	...	...	15.6	...	...	...	....	....
180	Sandstone	Wayne	20.4	1.9	4.6	4.0	3.0	2.50	160.5	5.50
181	Limestone	Butler	6.4	6.4	42.0	9.9	8.0	2.87	179.4	1.43
182	Creek Gravel	Butler	...	...	9.0	...	...	...	....	....
183	Limestone	Ripley	2.3	17.3	40.0	16.1	14.0	2.86	178.3	0.80
184	Chert	Ripley	5.6	7.1	52.6	11.6	9.0	2.50	157.3	5.19
185	Creek Gravel	Ripley	...	...	20.2	...	...	...	....	....
186	Quartzite	Ripley	3.8	10.5	29.8	15.7	16.5	2.90	186.5	1.49
187	Hill Gravel	Scott	...	...	38.0	...	...	...	....	....
188	Limestone	Scott	4.5	8.9	60.2	13.3	5.0	2.69	168.1	1.84
189	Chert	Scott	6.4	6.3	42.4	9.9	10.0	2.40	150.0	0.30
190	Limestone	Cape Girardeau	4.4	9.1	20.6	13.8	14.5	2 72	170.0	0.22

191	Sandstone	Cape Girardeau	5.3	7.5	40.6	12.5	12.5	2.36	147.5	3.54
192	Limestone	Cape Girardeau	7.0	5.7	39.0	10.7	12.0	2.69	167.0	1.01
193	Creek Gravel	Cape Girardeau	...	...	32.2	...	...	...	....	....
194	Limestone	Bollinger	5.7	7.0	46.6	9.1	6.0	2.56	160.0	4.70
195	Creek Gravel	Bollinger	...	...	14.0	...	...	...	....	....
196	Limestone	Madison	4.3	9.3	56.0	16.2	8.0	2.74	171.3	2.06
197	Ryolite	Madison	1.8	22.1	49.2	18.1	26.0	2.62	163.8	0.26
198	Kaolin	Madison	15.1	2.6	78.4	9.2	6.5	2.20	137.5	6.30
199	Granite	Madison	2.5	16.0	20.8	16.8	19.0	2.61	162.8	1.62
200	Creek Gravel	Madison	...	...	12.8	...	...	...	....	....
201	Sandstone	Madison	23.0	1.7	12.4	4.7	4.0	2.44	152.5	4.46
202	"Chats"	Madison	...	...	9.6	...	...	...	....	....
203	Granite	St. Francois	2.5	16.0	39.0	19.0	25.5	2.67	167.0	0.84
204	Granite	St. Francois	1.9	21.0	23.0	18.9	17.0	2.68	167.5	0.20
205	Granite	St. Francois	4.2	9.5	21.8	12.8	16.5	2.71	169.4	0.51
206	Creek Gravel	St. Francois	...	...	11.0	...	...	...	....	....
207	Chats	St. Francois	...	...	20.8	...	...	...	....	....
208	Limestone	St. Francois	4.5	8.9	21.6	10.1	13.5	2.87	175.6	1.53
209	Limestone	St. Francois	4.7	8.5	30.6	13.6	15.0	2.65	165.6	0.83
210	Sandstone	St. Francois	28.1	1.4	4.6	5.1	4.5	2.39	149.4	3.73
211	Porphyry	St. Francois	2.7	14.8	89.0	19.7	15.0	2.64	164.5	0.59
212	Granite	Iron	3.5	10.4	40.8	14.4	19.0	2.63	164.4	0.32
213	Red Hematite	Iron	5.6	7.1	36.2	17.2	13.0	3.89	243.0	1.22
214	Limestone	Iron	5.2	7.7	51.0	12.8	13.5	2.76	172.3	3.45
215	Porphyry	Iron	3.5	11.4	78.8	15.3	20.5	2.67	166.9	0.03
216	Creek Gravel	Iron	...	...	22.8	...	...	...	....	....
217	Limestone	Washington	7.4	5.4	40.4	13.6	10.0	2.79	174.4	0.52
218	Creek Gravel	Washington	...	...	9.0	...	...	...	....	....
219	Limestone	Jefferson	4.9	8.2	15.6	6.8	5.0	2.44	152.5	11.43
220	Creek Gravel	Jefferson	...	...	22.8	...	...	...	....	....
221	Limestone	St. Genevieve	3.8	10.5	28.6	9.9	6.0	2.69	168.1	1.50
222	Creek Gravel	St. Genevieve	...	...	56.6	...	...	...	....	....
224	Limestone	Perry	3.5	11.4	32.0	15.1	8.0	2.75	161.9	1.64
225	Creek Gravel	Perry	...	...	23.2	...	...	...	....	....
226	Creek Gravel	Montgomery	...	...	15.6	...	...	...	....	....
227	Limestone	Montgomery	5.3	7.5	117.2	4.5	5.0	2.66	166.3	1.33
228	Chert	Pulaski	4.4	9.1	45.6	10.7	12.5	2.65	156.7	1.25
229	Limestone	Pulaski	8.6	4.7	35.0	13.2	9.5	2.62	163.8	5.25
230	Limestone	St. Genevieve	6.3	6.3	32.8	13.7	12.5	2.69	168.2	0.50
231	Silica	St. Louis	...	...	36.6	...	...	...	....	....
232	Creek Gravel	St. Louis	...	...	17.6	...	...	...	....	....
233	Creek Gravel	Stoddard	...	...	30.0	...	...	...	....	....
234	Flint or Chert	Boone	5.9	6.8	17.4	...	...	...	....	....
238	Creek Gravel	Boone	2.6	15.4	52.2	...	...	...	....	....
239	Flint, "Chats"	Jasper	...	...	32.8	...	...	...	....	....
240	Rotten Granite	Iron	...	...	46.9	...	...	...	....	....
242	Limestone	Audrain	4.9	8.2	112.0	...	...	2.71	169.4	0.67

CONCLUSION.

From a study of these samples of road material and the results of the tests made on them, the following conclusions have been drawn.

Limestone is the most abundant and most widely distributed road material in the state; but unfortunately the tests show that only about 38% of the samples of this rock are classed as medium in wearing qualities, and about 62% are classed as low in wearing qualities, or too soft for roads, except for very light traffic. These soft limestones make a dusty road in dry weather and a muddy road in the wet weather. The dust produced by the wear of traffic is blown away by the winds or washed away by the heavy rains, so the stone is not protected by the dust from further wear. The automobile traffic also removes this fine dust from between the stones and the wind blows it away and causes the road to ravel. These conditions can be improved by the use of oil and the wear will be lessened to some extent. Nearly all of the samples of limestone show good cementing qualities and some are excellent in this respect; this suggests their use for a foundation for permanent roads where they are abundant and cheap; a harder and tougher material, such as creek gravel, granite or rhyolite, being used for the wearing surface. A finely crushed limestone of good cementing value might also be used as a binder for creek gravel which is often deficient in binding quality. There are also some localities where, for economic reasons, the foundation of a road might be constructed of a soft or brittle limestone and the wearing surface be constructed of a harder and tougher limestone with better wearing qualities, which was not so plentiful or had to be transported a longer distance.

The gravels in this state are derived from three sources, rivers and streams, glacial deposits, and residual deposits. From whatever source it may be derived, it is usually the hardest material to be found in the locality where it occurs as the softer materials have been disintegrated or worn away by the action of water and ice; it is therefore usually a good wearing material for road surfaces.

The gravel found in rivers and streams, commonly called creek gravel, is usually smoother and more nearly round than that in either the glacial or residual deposits, and contains very little or no clay. The chief constituent of the creek gravel in central and south Missouri is chert or flint which does not have good cementing qualities. On account of the low cementing value of these hard chert pebbles and the rounded shapes of the stones most creek gravel does not bond readily when placed on the road; but remains loose until a sufficient amount of loam, clay, or other foreign matter has been

carried onto the road to form a binder. The addition of clay will make a well bonded road, but this will cause the gravel to pick up in very wet weather and the road surface will be broken up by freezing and thawing as the clay will hold a large amount of water. It is thought therefore that the addition of a finely crushed limestone, or other stone of good cementing value, will greatly improve most of the creek gravels and form a well bonded and durable wearing surface.

The glacial gravels in Missouri are usually imbedded in clay and sand and the percentage of clay and sand is usually so great as to make it undesirable for road purposes. When the clay exceeds 30% the gravel is considered undesirable. A part of the creek gravel in the streams north of the Missouri River is of glacial origin, having been washed down into the streams by the erosion of the gravel beds.

The gravel which comes from the residual deposits are found throughout the Ozark region on the ridges and hills. This consists of angular fragments of chert or flint mixed with clay and it is known as hard-pan gravel or hill gravel. If the percentage of clay is not too great (less than 25 or 30 per cent) this material forms a hard and compact road surface. It is however easily eroded by water and requires quick and thorough drainage. On account of the clay holding so much water the road surface is liable to be broken up by freezing and thawing.

The best rocks in the state for road purposes are the granites, rhyolite, and porphyry found in St. Francois, Iron, Madison, Wayne, Carter, and Shannon counties. These rocks all have good cementing qualities and they are hard and tough enough to resist the wear of heavy traffic.

These tests are not to be considered as complete for all of the road materials of the state as some counties were not visited at all by the collectors and not all parts of the counties visited were examined; so there are many localities and many quarries in the state that are not represented in this bulletin. If any of the Highway Engineers, owners of quarries, or other citizens in the state interested in good roads, will send in samples of stone or gravel they will be tested by the Engineering Experiment Station and a report made on the results.

INSTRUCTIONS FOR SAMPLING AND SHIPPING.

In taking samples of stone from a quarry or ledge care should be taken to get a sound, fresh, unweathered sample representative of the interior stone.

When all material in a quarry is of practically the same variety, texture, etc., one sample will suffice. If however there are different

varieties in the same quarry separate samples of each variety should be taken and a report made on the position and extent of each. The stone should not be finely crushed.

In order to have sufficient stone to make the tests, samples should weigh at least 25 lbs. and one piece of each sample should measure not less than 3x4x5 inches in order that a core may be drilled therefrom.

The thickness of the ledge or the face of the quarry should be reported, also the extent of the country in which such stone is found. Report the name of the quarry, or the land owner's name, and the exact location of the quarry with reference to the nearest town or Post Office.

Samples of gravel should be taken with the sand or clay just as it occurs in the stream or gravel bank.

Ship in strong grain bags or tight boxes and mark each sample so it can be identified with the report, which should be sent by mail. To insure prompt and sure delivery ship by prepaid express to the Civil Engineering Laboratory, care of the University, Columbia, Mo.

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ENGINEERING EXPERIMENT STATION

VOLUME 3 NUMBER 1

THE USE OF METAL CONDUCTORS TO PROTECT BUILDINGS FROM LIGHTNING

BY

E. W. KELLOGG

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
March, 1912

INTRODUCTION.

There is a widespread popular belief that lightning-rods are of little or no value. Years may pass by without a single case of lightning stroke in a whole village or town of unrodded houses. On the other hand, one reads occasionally of a rodded building being struck and burned.

If rodded buildings are sometimes struck while thousands with no rods escape, what reason is there for supposing that rods give any protection?

It is clear that the rods do not give complete protection, but it may very well be that they reduce the danger of lightning stroke, giving a partial protection. Whether this is true or not can hardly be judged from the few cases that come to the attention of the individual. It must be tested by extended observations covering a great many buildings and a considerable period of time.

The reports of the Farmers' Mutual Fire Insurance Associations of Iowa and Missouri throw some light on this question. Delegates from the different counties meet each year in convention, and the question is asked:

"Did you have any losses from lightning on rodded buildings?"

The following table shows the experience in Missouri. The number of associations reporting no damage to rodded buildings gives an idea of the extent of the territory covered, while the heavy losses to other property caused by lightning, show that the lightning had by no means been idle, and the rodded buildings must have had plenty of chance to be struck. Nevertheless, during the three years there were only eleven cases of damage to rodded buildings in the State of Missouri, and in most of these cases the damage was slight:

	Number of Cases or Damage to Rodded Buildings.	Number of County Associations Reporting No Damage to Rodded Buildings.	TABLE NO. 1 Total Amount Paid Out for Losses from Lightning.
1909	1	Not stated in report	$29,755.23
1910	4	63	97,361.39
1911	6 none serious	62	91,678.95

The experience of the Iowa Farmers' Mutual Fire Insurance Association has been very much the same, only about one county in ten reported any cases of damage to rodded buildings, while nine counties out of ten had had some of their unrodded buildings struck and injured each year.

REPORTS OF THE IOWA FARMERS' MUTUAL FIRE INSURANCE ASSOCIATIONS.

Year.	Number of Associations Reporting Damage to Rodded Bldgs.	Number of Associations Reporting No Damage to Rodded Bldgs.	Number of Associations reporting Damage to Unrodded Bldgs.	Number of Associations reporting No Damage to Unrodded Bldgs.
1908	6	43	44	7
1909	3	36	42	3

In most of the cases of damage to buildings with rods the cause was found to be defective or incomplete rodding.

Still more instructive are the reports of amounts paid out by the Iowa Farmers' Mutual Fire Insurance Associations for damage by lightning.

FARMERS' MUTUAL FIRE INSURANCE ASSOCIATIONS OF IOWA.

Year.	Losses on Buildings and Contents Resulting from Lightning.	
	Buildings Rodded.	Buildings Not Rodded.
1908	$125.60	$46,010.22
1909	953.00	35,076.65
Total for 1908 and 1909.	$1,078.60	$81,076.87

These figures show that during these two years the unrodded buildings suffered nearly eighty times as much damage from lightning as those with rods. The total losses for four years, 1908 to 1911, show the unrodded buildings as suffering sixty times more heavily.

In order to arrive at a fair estimate of the protective value of the

rods, it would be necessary to compare the damage that occurred to a given number of rodded buildings with the damage to an equal number of unrodded buildings during the same period of time. There are probably about four unrodded to one rodded building in the State of Iowa—we are speaking of the larger farm houses and barns. Therefore, we must divide the $180,000 total loss on unrodded buildings by four, which will give $4,500 as the damage suffered by unrodded buildings equal in number to those with rods. To illustrate, suppose that the insured farm buildings of the State numbered 100,000, of which 80,000 had no rods. The loss on the 20,000 rodded buildings amounted to $3,000, and the loss on the 80,000 that were without rods was $180,000. The loss on 20,000 of the unrodded buildings would have been one-fourth of $180,000, or $45,000, which is fifteen times as great as the damage suffered by 20,000 similar buildings that were provided with rods.

The conclusion from these figures, then, would be that rodding reduced the damage from lightning to something like one-fifteenth part of what it was without the rods; and this, it should be remembered, was the result, not of the best possible system of rodding, but of good rods and poor ones taken together.

The lightning rod, however, has not proved as useful in this country as it might, on account of ignorance of its true value, and on account of the fact that rods have frequently cost a good deal more than they needed to.

It is unwise to rod some buildings, and it is foolish to leave some others unrodded. In some cases the cheapest system possible should be used; in others a better and more expensive kind of rodding is justified.

It is the purpose of this bulletin to set forth in an impartial way and as simply and clearly as possible, such facts as will assist the reader first, to decide wisely whether or not to rod his building; secondly, to enable him to understand how lightning rods operate and how they should be constructed, and to compare the merits of different rods and rodding systems; thirdly, to give such directions that any one who wishes can buy the materials and place a satisfactory system of lightning conductors on his own buildings; and lastly, to offer some other suggestions in regard to safety from lightning, which may be of value.

HISTORY AND DEVELOPMENT OF THE USE OF LIGHTNING RODS.

It was Benjamin Franklin to whom the idea first occurred that lightning might be the same thing, only on a gigantic scale, as the electric sparks a few inches long that men had produced in laboratories. Although the two seemed so different, Franklin noticed that they had some remarkable points of similarity. Artificial electric sparks are like lightning in the peculiar crooked courses they take, their suddenness, the color of the light produced, and the odor that follows. Both produce noise, can kill animals, set fire to inflammable materials, rend bodies which they pass through, and are carried easily by metals, but sometimes melt the metal if it is not large enough.

Franklin's Experiment.—With these facts in mind Franklin devised a scheme to draw a small quantity of the electrical energy (if it should really prove to be electrical) from a storm cloud. On July 4, 1752, he succeeded in doing this with the help of a kite; and the sparks he drew from a key suspended at the lower end of the kite-string were exactly like those that he had produced in his laboratory. Thus he demonstrated to his own satisfaction, and to the satisfaction of the whole scientific world, that lightning and electricity are identical.

Invention of the Lightning Rod.—The first use Franklin made of his discovery was to devise a way of protecting buildings from lightning. Having been a student of electricity for a number of years, he knew at once what the method of protection should be. He announced his discovery to the public in the pamphlet called "Poor Richard's Almanac," of which he was publisher, in the following words:

"It has pleased God in his goodness to mankind, at length to discover to them the means of securing their habitations and other buildings from mischief by thunder and lightning. The method is this: Provide a small iron rod, which may be made of the iron rod used by nailors, but of such length that one end being three or four feet in the moist ground, the other may be six or eight feet above the highest part of the building. To the upper end of the rod fasten about a foot of brass wire, the size of a common knitting needle, sharpened to a fine point; the rod may be secured on the house by a few small staples. If the house or barn be long there may be a rod and point at each end, and a middling wire along the ridge from one to the other. A house thus furnished will not be damaged by light-

ning, it being attracted by the points, and passing through the metal into the ground, without hurting anything. Vessels also having a sharp pointed rod fixed to the top of their masts, with a wire from the foot of the rod reaching down around one of the shrouds to the water, will not be hurt by lightning."

Growth in the Use of Lightning Rods.—Franklin and his friends immediately set to work to induce their fellow countrymen to place lightning rods on their houses. They set the example by protecting their own houses with rods. It was not a great while before some of these were put to the test. Mr. West, a Philadelphia merchant, was one of the first to provide his house with the kind of rod that Franklin recommended. A thunder storm occurred soon after it was finished and lightning struck the point of the rod. The stroke was witnessed by a number of people, who reported that they had also seen a flash near the foot of the rod. The house was not injured. On hearing of the flash at the base of the rod, Franklin concluded that the lightning must have left the rod because its connection with the earth was poor. By digging down a few feet he found that he was right, for the rod only reached down five feet and the ground around it was perfectly dry. He also examined the brass point and found that it had melted and run down much like the grease on a candle. Afterwards the brass or copper points were made of heavier wire and there was little further trouble of this kind.

A few cases such as this, where heavy strokes of lightning left houses uninjured, were enough to convince people that these rods afforded real protection. Nevertheless, there was a great deal of opposition to them at first and their use spread rather slowly.

The Situation in America.—About a hundred years later, when the value of rods was conceded by every one, an unfortunate state of affairs arose in this country. Hosts of unscrupulous men, pretending to be experts, traveled through the land selling worthless rods at ten times what the material in them cost, imposing on ignorant people, and leaving in their trail rods that were so carelessly erected that they were as likely to be a source of danger as protection. The ability of a simple metal conductor to ward off danger of lightning seemed so wonderful and mysterious that it was easy to persuade people that some peculiar form of gilded ornamental tip, or a special shaped bar was the real secret of success of the particular rod the agent happened to be selling.

In a book on "Lightning Conductors" by Richard Anderson, published in London in 1885, the situation in this country was described about as follows:

"America stands pre-eminent above all other countries in the

numerous schemes that have been devised for the protection of buildings from the effects of lightning, and probably no other nation has been so systematically victimized and swindled in the matter. The tramping 'lightning-rod men' of the United States have been notorious for extortion and ignorance; they use all kinds of fantastic and peculiar shaped terminal rods and conductors, the main object apparently being to make as great a show with as little material as possible. Their work is almost entirely confined to the upper portion of the conductor, to the absolute neglect of the most important part—the earth terminal. The majority of the lightning conductors in America are consequently untrustworthy; very often they are practically insulated by the dry soil from the ground water, to which the lightning must find its way. They are therefore in such cases more a source of danger than a protection. Unhappily these traveling impostors are by no means extinct, although increased knowledge is gradually driving them out of the field."

It was natural that after such experiences as these, people should distrust all salesmen of lightning rods, and doubt whether any rods were of value. Lightning rods came to be regarded very much as "gold bricks," as a sign of ignorance on the part of the buyer. The man who bought a rod was ridiculed and the rod itself considered as a joke.

Fortunately a more healthy state of affairs in this respect is gradually coming about. In cities and towns there does not usually seem to be much need of lightning rods, but in the country there is still considerable destruction by lightning, and the rod is recognized as its true worth. Greater intelligence on the part of the farmer and reasonable caution enable him to buy what he needs in the way of a lightning-rod without being swindled. Besides the ignorant "frauds" who are still found occasionally, there are respectable companies making and selling lightning-rods, who know their business and do not make unwarranted claims for their rods. The best way to distinguish between the agent who represents a respectable firm and the "quack" is to learn as much as possible about lightning and lightning

protection by reading, and to compare the statements of a number of different companies before buying. One fairly good test is to find out how much pains the company takes in getting a good ground connection. This part is very important, and is hidden under ground. After the rod is in place no one knows whether the ground connection is good or bad. The representative of the firm which really seeks to protect the buildings of its customers will take great care to secure the best possible ground connection.

ELECTRICITY AND LIGHTNING.

Fundamental Facts About Electricity.—Electricity is a form of energy that shows itself in two different states—stored electricity and electricity in action or flowing.

Charges.—Electrical energy can be locked up or stored, and is then spoken of as an "Electric Charge."

Insulators.—In order that it may stay imprisoned it must be surrounded by some material through which it can not pass. Such materials are called "insulators" or "non-conductors," and a few of the most common of these are: air, glass, rubber, oil, marble and slate. Many other substances, such as paper, wood, sand, clay and stone are fairly good insulators, provided they are perfectly dry.

The following table gives some common materials arranged in order of their conducting power:

Good Conductors.	Poor Conductors.	Poor Insulators	Good Insulators
Copper	Solution of salt or lye	Porous stones	Dry gas or air
Aluminum	Dirty water	Dry earth	Varnish
Iron	Clean water & ice	Dry wood, leather or paper	Glass
Lead	Substances containing water, such as plants, animals and moist earth.	Oil and grease	Rubber
Other metals		Silk	Sulphur
Graphite		Paint	Mica
Charcoal and Coke		Dry sand	

Conductors.—There are other materials, however, through which the electricity can pass with more or less ease. Such materials are called "conductors."

By "good conductor" we mean one that offers very little obstruction or "resistance" to the passage of electricity. The other materials named as conductors show resistances hundreds or thousands of times greater than that of metals, but they may still be classed as conductors. Dirty or salty water is a much better conductor than pure water.

The word "conductor" is also used to designate any piece of conducting material, and it is frequently used here in the special sense of lightning rod.

Charges Reside in Conductors.—When charges of electricity are found they are nearly always in some body of conducting material that is surrounded by an insulator, such as a metal plate in air. In nature the stored electricity is in the cloud which consists of minute drops of water, and it is imprisoned by the surrounding air, which is an insulator.

Two Kinds of Electric Charges.—There are two kinds of charges, which are respectively called "positive" and "negative."* Taken by

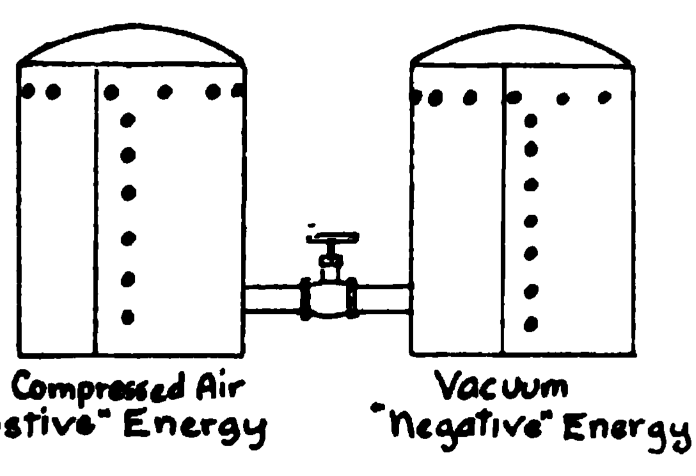


Fig. 1. When the valve is opened the two kinds of energy neutralize.

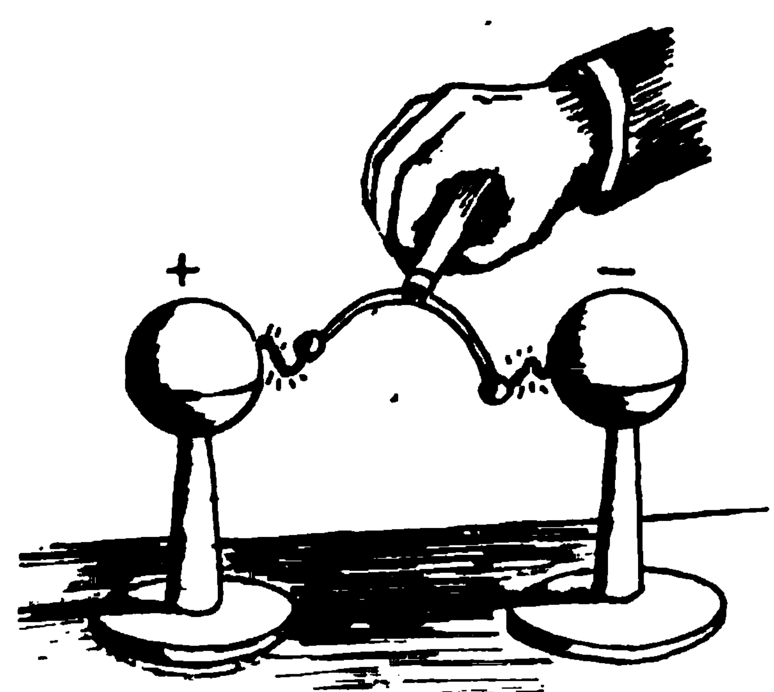


Fig. 2. Discharging a pair of charged conductors.

*We might compare a positively and a negatively charged conductor to two tanks, one with air under pressure and the other with the air pumped out. Both tanks represent stored energy. We could attach a steam engine to the high pressure tank in place of a boiler and the engine would run. We could also run the engine for a few strokes by means of the vacuum tank by connecting the exhaust pipe of the engine to the tank and leaving the steam pipe open to the atmosphere. The air from outside would be drawn through the engine by suction and make it run. Hence we can say that the vacuum is just as truly stored energy as is the compressed air. Both tend to break the tank if it is weak, and both can be made to run the engine.

But if the two tanks were connected together by a pipe, the two kinds of energy would neutralize each other, just as the two charges of electricity neutralize.

themselves they are very much alike, and it is not easy to tell which is which; but they behave differently towards each other. A piece of material having a positive charge will repel another piece which is positively charged, and the same is true of two negative charges; but if one has a positive and the other a negative charge, they will attract each other. When a positively and a negatively charged body are placed near each other, not only do the bodies attract with considerable force, but the charges themselves get as near together as possible by concentrating in the parts of the charged bodies that are nearest together.

Discharge.—If now a wire is stretched across from one charged conductor to another, an electric current flows through the wire from the body that has the positive charge to the one that has the negative charge. After this passage has taken place there is no charge of any kind left. We say that the opposite charges have "neutralized" each other.

Breaking Through an Insulating Material.—Whenever there is a positive charge of electricity, there must also be a negative charge somewhere not far away. The one is never found without the other, and the electricity is trying to get across from the positively charged body to the other. If a cloud is carrying positive electricity, either the earth or else some other cloud is carrying a corresponding amount of negative electricity. If a wire or rod could be placed across from one to the other, the electricity would instantly make use of it to get across; but it does not wait for any wire, it "breaks" through the air that separates them, very much as the water in a pond may break through a dam. Whether it can do this or not depends on the distance it has to jump and the intensity of the charge, or in other words, the "electric pressure."

Electric Sparks and Lightning.—If electricity breaks through the air in this way on a small scale, it is an electric spark. If it occurs in nature between clouds or between a cloud and the earth, it is a lightning flash.

Electric Strain.—Just before it breaks down the air is said to be "electrically strained," for in some ways the behavior of an insulator seems like that of a piece of solid material which is strained and finally broken. After it has broken down, the air is really a conductor, although a rather poor one. When it has cooled off, it again becomes an insulator.

Value of Points.—Besides the discharge that occurs by the electricity breaking through the air, there is a perfectly quiet and harmless discharge that takes place more slowly, from any sharp edged or pointed conductors that reach up toward the cloud and are connected with the earth by a continuous line of conducting material.

By neutralizing the charge in the cloud in this way a direct stroke of lightning may frequently be prevented. When a point is discharging electricity very rapidly, a faint blue haze appears right at the tip and there is a smell of ozone.

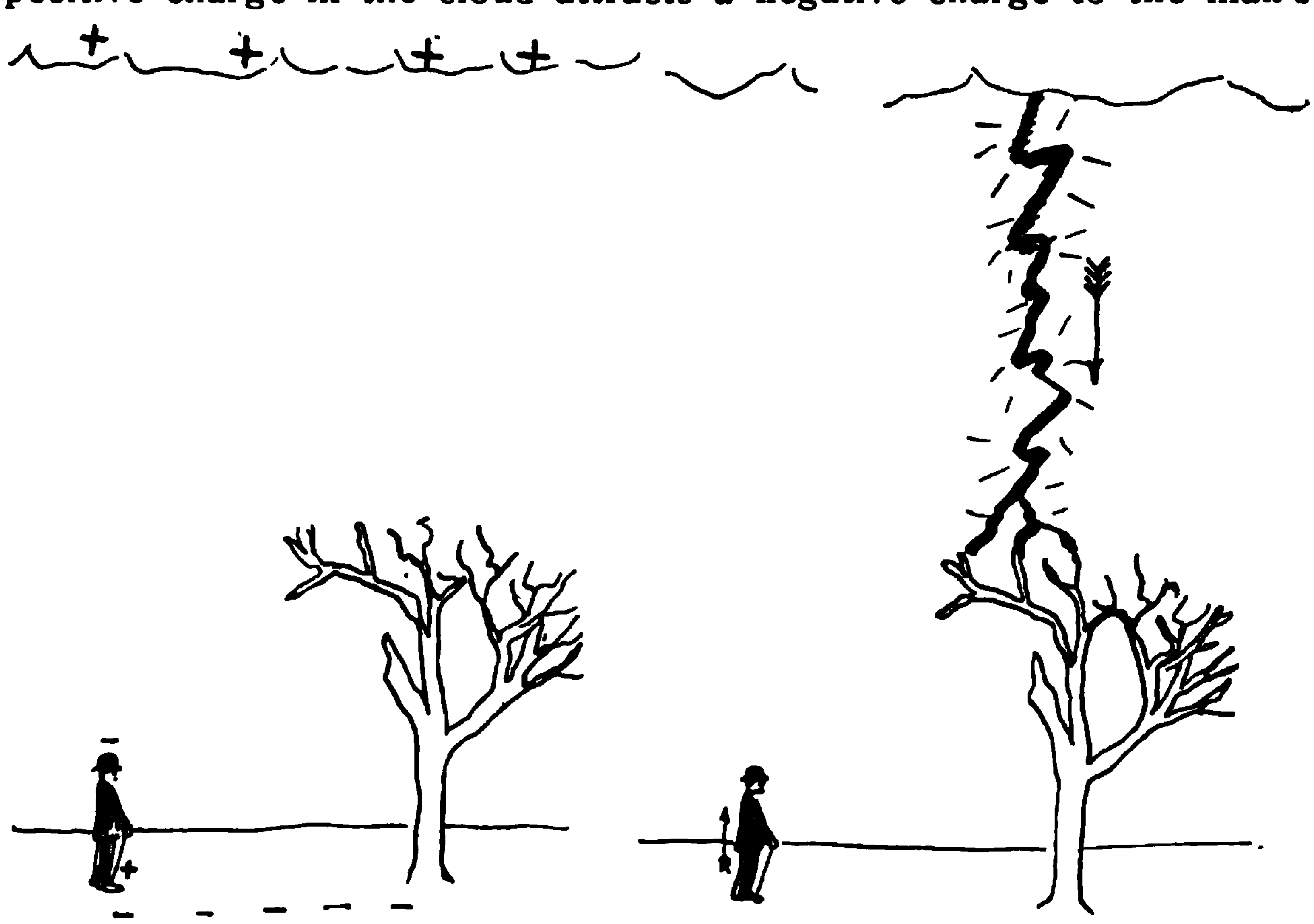
Where Lightning Occurs.—There are probably twenty lightning flashes between clouds to one between a cloud and the earth. The most frequent discharges occur near the front edge of the advancing storm. The places that are most likely to be struck are hill tops and other high objects, such as buildings. Lightning strokes are also more frequent in the neighborhood of bodies of water and over swamps. Where the earth is a good conductor there is more likelihood of lightning than where it is a poor conductor. For this reason moist soils and high ground-water level, as well as the presence of coal or iron ore tend to increase the danger of lightning. Smoke and some kinds of vapor seem to reduce the insulating power of the air, making lightning strokes more probable. The vapor from hay stacks and hay stored in barns appears to have this quality, as hay stacks are notorious for the frequency with which they are struck. A column of hot smoke is believed to form an easy path for a lightning discharge. But the smoke may have a beneficial effect, for the minute particles of soot carry away some of the charge from the earth and neutralize the charge in the cloud, accomplishing in this way the same valuable work as lightning rod points. So while a chimney may be more liable to stroke than surrounding objects of equal height, yet the fact that it is sending out smoke and hot air makes it less likely that there will be a stroke at all. The chimney protects its neighbors better than itself. This presence of numerous chimneys probably accounts to some extent for the small amount of damage from lightning in towns and cities.

Destructive Power of Lightning.—Wherever the lightning discharge goes it produces heat. The poorer the conductor through which it passes the greater the heat. A good metallic conductor of sufficient size will carry the current with comparatively little heating. It will get hot, to be sure, but not hot enough to do any harm. Now when lightning passes through stone and wood it develops great heat because they are poor conductors. If they contain moisture, it is instantly turned into steam and blows them to pieces. Wood is very likely to catch fire if it is dry enough to burn; and metal objects may be melted. When a flash passes from the air into a metal conductor, the conductor is apt to be melted at that point, but the heat which melts it is not produced in the metal, but in the air right next to it.

Shock from Lightning Without Being Struck.—People are very frequently knocked down or shocked when a flash of lightning oc-

curs, and yet it appears afterwards that the lightning did not pass anywhere near them. It would not be unnatural in such a case to feel like accusing them of imagining their sensations, but the experience is not necessarily imaginary at all.

A lightning stroke always results in a sudden change in the electrical condition of the cloud. Usually the charge in the cloud is actually reversed a number of times in a very small fraction of a second. Suppose the cloud over a man is positively charged, and the earth is negative. Since the human body is a conductor, the positive charge in the cloud attracts a negative charge to the man's



Shock Without Being Struck.

Fig. 3. a. Just before stroke, + indicates the presence of a positive charge; — indicates the presence of a negative charge.

Fig. 3 b. During stroke. Arrow indicates the flow of electric current.

head, while the negative charge of the earth draws a positive charge to his feet. Now a lightning flash occurs somewhere near and in an instant the earth becomes positive and the cloud negative. The charges in the man will have to reverse at the same time, which means that a current of electricity passes from one end of his body to the other, and this is enough to give him a more or less violent shock.

The Course Taken by a Lightning Stroke.—The course that a discharge will take is already practically determined before it occurs. Just before a flash between a cloud and the earth the air is under an "electric strain," and this strain is more intense in some places

than others. The cloud is more highly charged at some points than at others, and as the mist condenses into rain the pressure keeps rising. The various objects on the earth are more or less charged and here and there are objects which are fairly good conductors. The distribution of electricity in the cloud, the presence of conductors and the presence of charged objects projecting above the earth all have a share in determining certain paths between the cloud and earth where the electric strain on the air is greatest. Then, the air is weaker along some lines than others, due to the presence of impurities and to moisture. These two factors together, intensity of strain and weak spots in the air, determine where the lightning strikes and what course it takes.

Does Lightning Strike Twice in the Same Place?—The saying that "lightning never strikes twice in the same place" is altogether wrong. Numerous examples are known of lightning striking the same place not only twice, but many times. In fact, a place that has been struck once is more likely to be struck again than a place which has never been struck. Of two similar houses, one of which has been struck and the other not, the one that has been struck is in greater danger during a storm, not because it has been struck, but because the same reasons that caused the lightning to select this house in the first place may still be present.

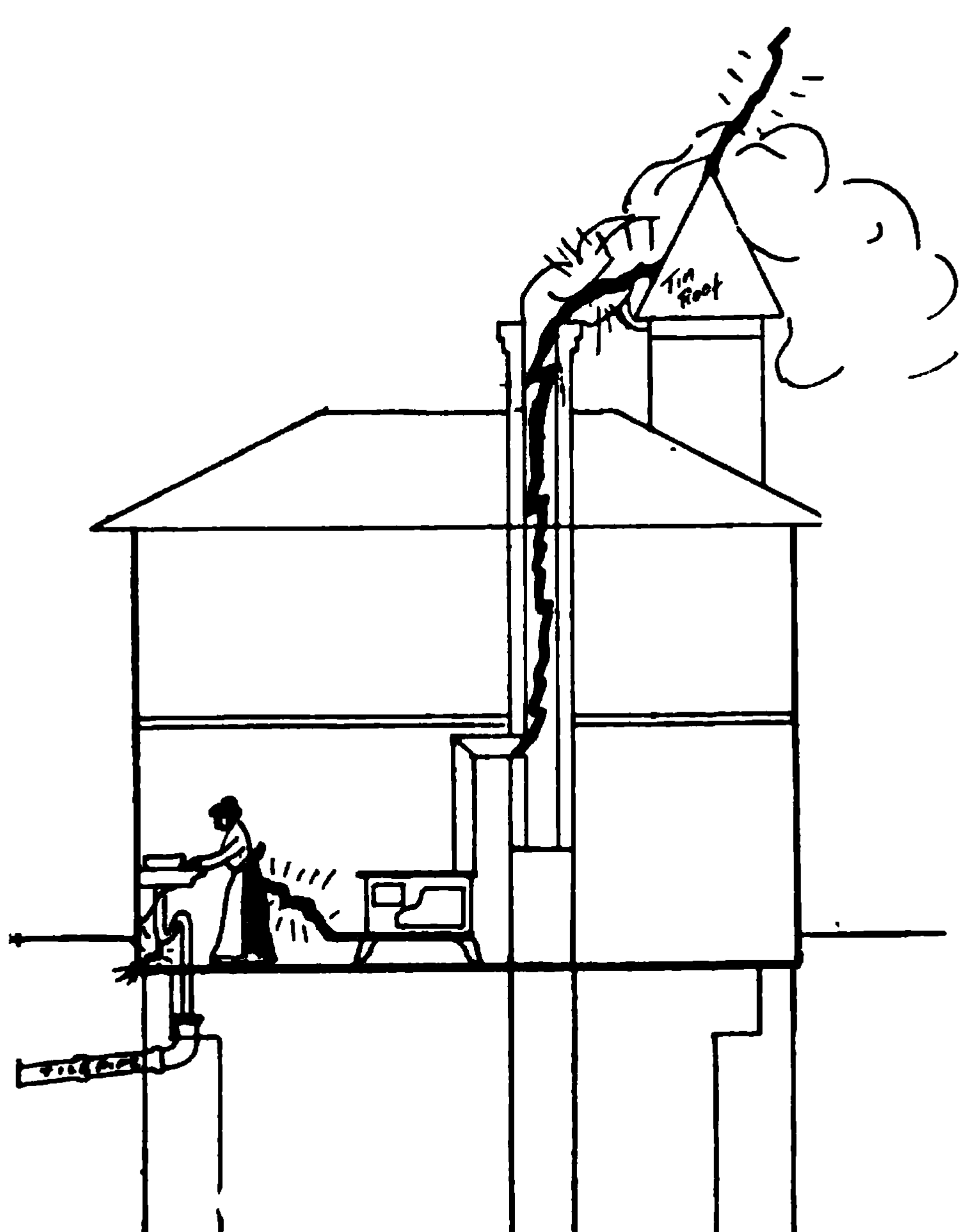


Fig. 4. Example of path taken by lightning.

Behavior of Lightning in a Building.—If lightning strikes a house that it not provided with a lightning conductor, its course is determined by what conductors it can find, by the electric charge on the various objects in its way, and by the insulating strength of the air and other materials that it has to break through. Usually it will be found

after the stroke has passed that it has used any conductors that would help it on its way to the ground, jumping from one to the other when necessary at the point where they were closest together. For instance, it may strike a chimney, travel down the soot-covered inside, which is a fairly good conductor, along the stove pipe, through the stove, jump several feet through air to get to the sink, and pass down the drain-pipes to the earth. Another example, is a church, the steeple of which was struck. The lightning made use of a long iron rod used as a brace in the steeple structure. From the lower end of this it jumped to the clock works, which carried it as far as the clock face, where it jumped several feet to the lead flashing in a roof-valley. This lead flashing carried it to the roof gutter, which was metal, and the rain pipes took it to the ground.

If lightning strikes a lightning rod it will in all probability follow the rod into the ground, but if the ground connection is bad it is likely to take other paths. Even in the case of a good ground connection, it must be remembered that there is an enormous difference in electrical pressure between the top of the rod and the ground. This pressure may be sufficient to cause the lightning to jump from the rod to other conductors if there are any near, and send at least a part of the current that way. This is what is called a "side flash," and is of frequent occurrence. A good example of a side flash was a case when a man had a gun leaning against the wall in his house, directly opposite the lightning rod outside. The lightning passed through the wall to reach the gun, and from the butt of the gun struck through the floor to the ground.

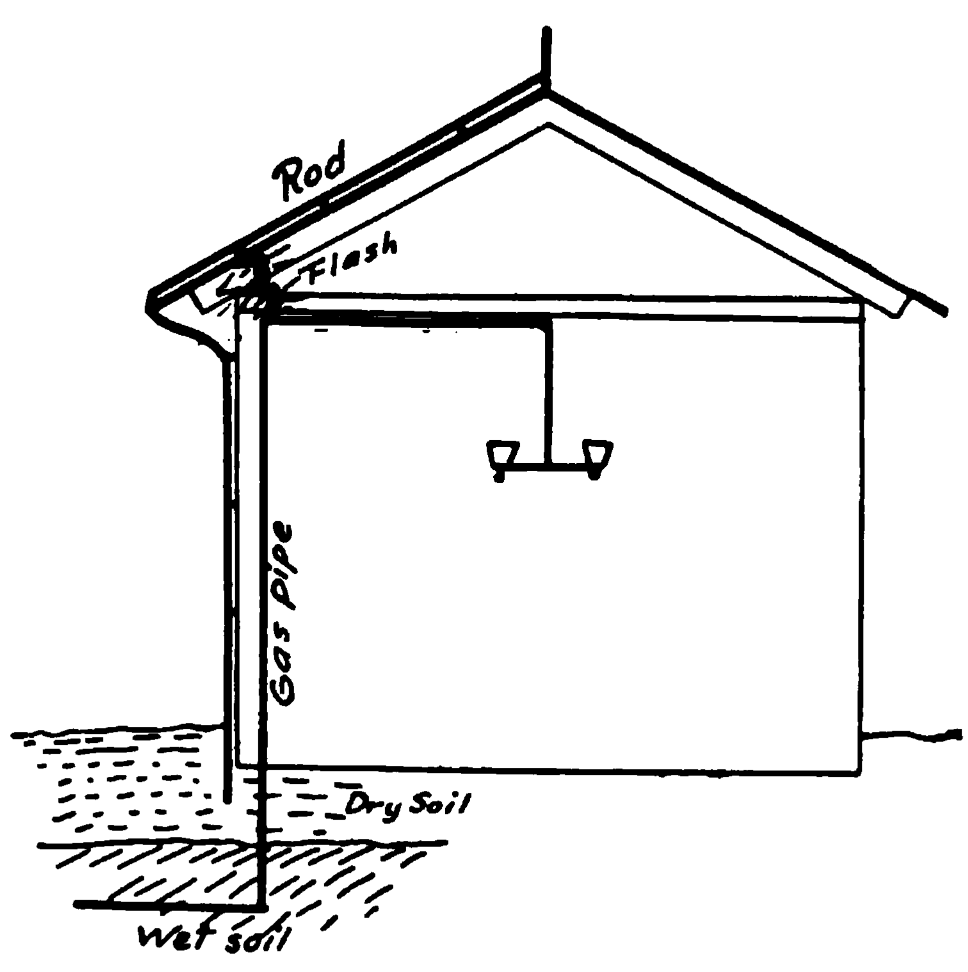


Fig. 5. Example of a side-flash.

Wherever the lightning can travel through metal, and the metal conductor is not so small as to be melted, no harm is done. Wherever it passes through other things it is likely to shatter them. Hence if there is any likelihood of lightning jumping from one metallic conductor to another, a good

metal connection should be provided so that the passage will not be attended by damage. Chains of conductors formed in this way must be complete all the way to the earth. For instance, if the roof gutter is connected to the rod it is still more important to provide a good ground connection from the bottoms of the rain spouts. Water and gas pipes have excellent connections with the ground, and if they pass anywhere near the lightning conductor they should be connected with it by metal. If the gas pipes are made of lead, however, they should kept well away from the lightning rod, as the lead may be melted even though there are good metallic connectors to it.

Lightning avoids roundabout paths whenever it can take a short cut, even though the short cut is of poor conductors and involves breaking through considerable air and other insulating materials.

In designing lightning conductors three things must be kept in mind:

1. Lightning is likely to make use of any metal that lies anywhere within reach and may do considerable damage in getting to and from this metal.

2. Lightning has a very strong tendency to split up and go part one way and part another. If the system of lightning conductors provided for it is arranged to permit it to do this, the danger of its taking other courses that were not intended is greatly reduced.

3. Lightning seeks as direct a path as possible. It might be compared to a man who is in a great hurry to get to a certain place. He prefers good roads if there are any, but will not go much out of his way for the sake of good roads, and even cuts 'cross-lots to save a little distance.

Again, it might be compared to a railroad passenger going to a distant city. If he can take a through train he will use it, but if any time is saved by going part way on one train and then changing cars, he will do that. The destination of the lightning is the ground. If a single continuous conductor will take it all the way, it will use that conductor, but if a more direct route is offered by several disconnected conductors, the lightning is apt to take the short cut, even if it has to make several jumps.

A rule adopted by the Royal Institute of British Architects is, that the length of a lightning conductor between any two points must not be more than one and one-half times the length of a straight line between these same points.

Resistance Not the Only Factor.—The great suddenness with which a lightning stroke occurs causes it to act very differently in a lightning rod from the way the electricity which supplies our electric lights would act. The dangerous "side flashes" that sometimes occur are because the electricity cannot get through the rod

as fast as it wants to, and consequently finds other ways to get to the ground. But the trouble the lightning encounters in getting down the rod is not due to the "resistance" of the rod (which depends on the size of the rod and the material of which it is made) half so much as it is due to the difficulty of getting a big electric current started through the rod in so short a time. In this respect it is something like a gun. The tremendous pressure behind the bullet is not necessary merely in order to overcome the friction in the barrel, but to get the bullet started in a very short time.

For this reason the importance of using heavy copper rods, which give very low resistance, has been over estimated. So far as danger of side flashes is concerned, there is little choice between an iron wire 1-8 of an inch thick and a copper rod a half-inch in diameter (There are, however, other advantages in favor of the large conductors, namely, less danger of their being melted, and longer life.)

The only real way to provide an easy path for the lightning and thus reduce the danger of side flashes, is to use several rods or wires connected together at the top so that the lightning can use all of them at once.

(See illustrations of rodded houses on pages 27 and 28 noting that wherever the lightning strikes it will find at least two ways to get to the ground.)

The farther apart these conductors are placed the better. Two wires twisted together are hardly better than a single one. An inch apart they are considerably better than one, a foot apart still better, and if twenty feet apart they offer hardly more than half the obstruction that a single wire would offer. Two wires placed twenty feet apart are better in this respect than twenty wires twisted into a cable. Three, four or five conductors may be used in this way to advantage, but it is essential that each one be provided with a good ground connection.

Only the Outside of the Conductor Is Used.—There is another effect which results from the great suddenness with which lightning comes on, and which is important in designing lightning conductors. Just as the electric current tends to split up and go down part one way and part another when there are several paths provided, so the minute streams that are flowing in a single rod or wire try to get as far apart as possible, with the result that all the electricity flows close to the surface of the conductor. If the latter is in the form of a round bar the current flows just in the "skin," if the bar is square the electricity crowds into the corners, or if in the form of a flat strip the two edges carry almost all of the current. If, instead of being a solid piece, the conductor is woven or twisted out of a number of smaller wires, the same thing holds true. The outside wires carry all, or nearly all, the current. If the conductor is so woven that the same wire is outside at one point and inside at another a slight advantage may be gained, but in general the current of electricity will cross from one wire to another so as to always keep on the outside.

Large Conductors Waste Material.—From this it is evident that the material in the interior of a conductor is wasted, is just so much dead "filler," and the larger the rod, the smaller the proportion of the material that actually does the work. Thus a very fine wire uses all its material, while a rod a half-inch in diameter would use less than a tenth of the material in it. A thin tube would serve just as well as a solid bar of the same size, so far as conducting the electricity goes, and tubes have been used, but they are frail and difficult to handle. Besides this, the metal in the interior, while it does not help conduct the electricity, does help to absorb the heat that is produced in the outer layers. Since the heat is produced so quickly that the air around the rod can not carry it away in time to prevent the rod from getting hot, this heat must be absorbed by the metal of the rod, and a certain amount of metal is necessary to absorb it.

A tube might melt, when a solid bar of the same size would be uninjured.

The only object then of using heavy conductors is to avoid the danger of their melting, and experience is the only guide in determining what sizes are necessary. But if instead of putting all the material into one conductor, several smaller ones are used, so that the current can split up and go part one way and part another, not only is the heat developed in each so reduced that there is less danger of melting, but a larger part of the material is useful in conducting the electricity, and a much easier path offered for the lightning to get to the ground.

Character of the Protection Afforded by Rods.—The protective power of lightning rods is three-fold; first, the preventive effect of the silent discharge from the points; secondly, that the rod, if an actual stroke occurs, will carry the lightning harmlessly to the ground; and in the third place there is less danger of persons or animals inside the building being injured by the shock (described on page 14) that is sometimes received by those who are not actually struck. The value of the points is universally conceded. They cause a gradual discharge that reduces the chances of a direct stroke occurring, though they can not always prevent a stroke. It takes time for the points to get in their work, and there are frequent cases where the conditions that cause a stroke come about so suddenly that no amount of pointed conductors would prevent it. Such a condition arises when the cloud over a building remains unchanged for some time and then is suddenly charged with electricity by a lightning flash between it and another cloud.

Examples of buildings struck in spite of pointed conductors are no argument against the points

Do Lightning Rods Attract Lightning?—The question will naturally arise whether a conductor reaching up toward the cloud does not actually invite the lightning stroke. The answer is that it probably does to some extent. But it attracts the lightning only to itself It can never in any case make the danger of some other part of the building being struck greater than without the rod. A number of cases are known in which

lightning had struck the rod and the people within the building had known nothing about it exceut that somewhere near by there had been a brilliant flash of lightning with loud thunder. The discovery next day that the points of the conductor has been fused showed what had happened. If the rod, however, is not such that it can take care of the discharge harmlessly when it is struck, it may be worse than nothing. But the question of whether the rod invites the lightning, makes a stroke more likely than before or not, is of minor importance. Experience has shown conclusively that it accomplishes its purpose, and that it is very rare indeed for a properly rodded building to be damaged by lightning.

LIGHTNING RODS AS INSURANCE.

Degree of Protection Afforded.—The question whether lightning rods afford protection was discussed in the introduction, and it was seen that the experience of the Farmers' Mutual Fire Insurance Companies indicates that rodding reduces the danger of lightning stroke to a small part of what it was before.

Wherever extended observations have been taken and accurate records kept the experience has been the same In the province of Schleswig Holstein in Europe, rods are used very extensively, yet the records of fire insurance companies between the years 1870 and 1878 showed that while 552 buildings altogether were injured by lightning, only four cases were reported of injury to buildings that were provided with rods, and these rods were not in good condition.

If a building is equipped with a well designed system of lightning conductors the danger from lightning is so exceedingly remote

that the claims of many lightning rod companies that "No building furnished with our rods has ever been injured," may very well be true. It may also be true that companies can afford to guarantee that no losses will occur on buildings which they equip with rods. It is to be doubted, however, whether such guarantees are in such a form that money could be legally collected from the companies in casé of loss by lightning.

Extent of Damage from Lightning.—Having seen that danger may be reduced to practically nothing by good conductors, we may consider the question: "How serious is the danger without lightning conductors? Is the danger great enough to make it worth while to spend the money for conductors?"

These are the questions which are left to the judgment of the owner. He must decide according to his own feelings, his experience and observation of destruction in his vicinity, and such knowledge as he has in regard to the special conditions that make the danger to his buildings greater or less than to other buildings. A few facts are given here that may assist him in deciding the question wisely.

In cities and towns ordinary buildings are in so little danger that lightning rods are rarely installed. In villages the danger is greater; considerable damage is done in smaller towns, but not nearly so much as in the country. The isolated buildings on farms are by far the greatest sufferers from lightning. Some statistics have been gathered which seem to indicate that the danger from lightning is four to five times greater in the country than in the city.

The reports of the Farmers' Mutual Fire Insurance Companies of Missouri give the following figures of losses paid out during the three years, 1909 to 1911:

Year.	Total Losses.	Losses from Lightning.
1909	$237,202.38	$29,755.23
1910	281,726.37	97,361.39
1911	341,471.04	91,678.95
Total	$860,399.69	$218,795.57

From this it is seen that one-fourth of all the losses are due to lightning. The total cost of insurance comes to about 28 cents per year on every $100.00 worth of insured property. Since one-fourth

of the losses are due to lightning, it would cost in the neighborhood of seven cents per year on every $100.00 worth of property, to insure against lightning alone.

This figure, however, does not correctly represent the risk to unrodded buildings. Seven cents per $100.00 is the cost of insuring rodded and unrodded buildings indiscriminately, whereas practically all the damage occurs to buildings without rods. Since the Farmers' Mutual Companies make no reduction in rates at present in favor of buildings protected by conductors, the rodded buildings are charged more than enough to pay for their own losses, while unrodded buildings pay less than the cost of their own insurance. If the unrodded buildings were charged a rate that would pay for their own losses, this rate would have to be considerably higher than seven cents per $100.00. It is impossible to say what proportion of the buildings insured had lightning rods. If 70% of the buildings insured were without rods, and had to pay a rate that would cover the cost of insuring them this rate would have to be 10 cents per $100.00 instead of 7 cents.

The figure, 10 cents per year for every $100.00 of building value, may perhaps be taken as a fair average of the risk to unrodded farm buildings throughout the State. To state it differently, there is one chance in a thousand that your unrodded building will be completely destroyed by lightning within the next year.

Based on this estimate you would be warranted in spending $1.00 a year to protect a building worth $1,000.00. Since $1.00 is the annual interest on about $20.00, it would be worth while to spend $20.00 on a lightning rod for a building worth (with its contents) $1,000.00, $40.00 on a $2,000.00 building, and so on.

Since the insurance companies make no difference in rates, it would seem at first sight that it would be better policy and cheaper to simply keep the building insured and let the insurance company take the risk. In some cases this is true, but there are many considerations that make it worth while to equip buildings with rods, even though it is a more expensive kind of insurance than that offered by insurance companies.

The Principle of Insurance.—The usefulness of insurance is based on the fact that a man can better afford to bear a slight loss that occurs regularly and that he can figure on, than to sustain a single heavy loss that he can not foresee. The small losses are to be sure, a drain on a man's resources, but a sudden great loss may rob him, not only of his property, but of his means of earning. A barn burned may mean not only the loss of the barn, but a crop ruined for lack of space to store it. Horses and tools missing when they are in greatest demand may mean heavy losses in the crop.

These things are not paid for by insurance companies, neither will they repay even the full value of the building itself and what was in it. Hence an additional insurance may be worth while.

So valuable is it to a man to eliminate chance, and to know beforehand exactly what expenses and losses he will have to meet, that it would pay him to insure his property even if the insurance company charged twice as much as it cost them. Fortunately this is not necessary, as insurance can be had nearly at cost. The less property a man has the more he needs to insure it. The millionaire can afford to be his own insurance company, but the farmer with a single house and barn can not.

Two Kinds of Insurance.—Insurance against losses may be had in two ways, either by spending some money in order to prevent the loss from occurring, or by contracting with an insurance company to have the company stand the loss if it does occur. The first kind of insurance might be call **preventive,** and the second **compensating.**

Preventive insurance may or may not be more expensive than the other, but it is more valuable. Compensating insurance never repays to the full extent of the damage, it **reduces** the loss to the individual, but does not prevent it. He still loses something and the losses that were not and could not be covered by the policy may be serious.

Insurance which pays for prevention, on the other hand, makes it unnecessary that the owner should bear any loss beyond the cost of the preventive measures. Besides

this, there are things that can be insured by this method, for which the compensating insurance is altogether inadequate. A few thousand dollars is poor pay for the loss of a life. A life insurance policy will not take the place of a good doctor. Yet a wise man makes use of both. Many a house has been struck and some members of the family killed. Fire insurance companies do not repay those that are left for what they have lost, but lightning conductors might have prevented the loss.

Where Protection Is Most Needed.—To illustrate the cost of insurance against lightning we used the figure 10 cents per $100.00, or one chance in a thousand of complete destruction each year, but this estimate is an average for the entire State, and must not be taken as correct for all places. The danger may be much less in many places and may be five to ten times as great in others. Many counties showed averages twice as high as that for the State. The people living in a locality are perhaps the best judges of whether lightning damage there is unusually heavy or not. In hilly country thunderstorms seem to follow definite courses, so that certain places are visited by storms much more frequently than others. Storms are apt to travel along over valleys, over rivers and over lakes and swamps, in preference to other places, and for this reason buildings near such places are in greater danger. Build'ngs on hillsides and also large structures in the open country that stand out by themselves are especially likely to be struck by lightning. Barns in which large quantities of recently cut hay are stored are believed by many to be more in danger from lightning than at other times.

Large trees close to a house may or may not make the house safer than it would be without them. It is not wise to rely on them as affording much protection.

Summary.—To state briefly the considerations which determine what expenditure would be justified in equipping buildings with conductors, or whether they should be equipped at all, the following questions must be settled:

1. What is the chance of injury to the building?

2. Is it sufficient to insure it against lightning in a fire insurance company?

3. What losses might occur in case of lightning that would not be covered by the policy?

4. Does the building at some times of the year represent such a large part of your property that its destruction would be a very serious matter, ever though most of its value were paid you in cash?

5. Does your fire insurance company make any lower rates on buildings that are protected by rods?

6. Does the building contain persons or things whose loss could not be compensated for in money?

7. Would the personal satisfaction of knowing that your property was in no danger from lightning be worth more to you than simply to know that the loss would be refunded in cash?

It was seen that where storms are not unusually frequent lightning rods may be a somewhat more expensive form of insurance than the kind which insurance companies afford, and if the building is one whose loss would do no great harm beyond the cost of rebuilding, it would probably not pay to provide it with lightning conductors.

If, on the other hand, a lightning stroke would mean loss, either of life or property which would not be repaid by the cash value of the policy, the building ought to have both kinds of insurance—lightning conductors as well as fire insurance policy. This would be especially true of tall structures that are likely to be marks for the lightning, and of buildings situated in places where storms are frequent.

ARRANGEMENT OF CONDUCTORS.

In order to protect a building from lightning, lines of metal conductors must be run from the prominent points of the building, as directly as possible to the ground. Conductors should run along the roof ridges and up above the tops of cupolas and chimneys. If the roof is flat or has small pitch, conductors should be run along the eaves. Next to chimneys and cupolas the points most in danger are gable ends and dormer windows. The conductors on the roof must all be connected together and run down to the ground at several places, say at the corners, and buried deep enough to ensure an easy path for the discharge to get away into moist soil. If a metal roof is used it must be connected with the ground by wires and no further conductors are necessary except at chimneys, where a short rod should be run up a foot or so above the top, and should be soldered to the roofing at the bottom. Soldered joints must be so made that even if the solder were melted the parts would be held together otherwise, as by staples or wire.

If the rain gutters are of metal they will serve as a conductor as long as they are in good condition. The tin rain spouts will carry the discharge toward the ground as far as they go, and a good connection must be made to them at the bottom, with conductors that run well into the ground.

It is not uncommon to use sheet metal flashing along the hips

and ridges of the roof and also in the valleys in order to insure a tight roof. If the lines of metal formed in this way are unbroken, they form in themselves a good system of lightning conductors, provided they are connected at their ends to rods running to the ground. It is best, however, not to let this flashing or the rain gutters and spouts take the place of rods, except on less exposed parts of the building.

The tin roof of a cupola should be connected by several stout wires to the tin roof below, or if the main roof is of shingles or slate, a grounded rod should run direct to the cupola. Ornamental iron work on a roof should be connected to one or more rods leading to the ground.

In short, all metal work on the roof, except very small pieces, should be made a part of the system by connecting it to the other conductors. The connection to any piece of metal should be at its lower edge or end.

Some illustrations are given showing good arrangements of rods for several styles of houses. The general idea is to cover the

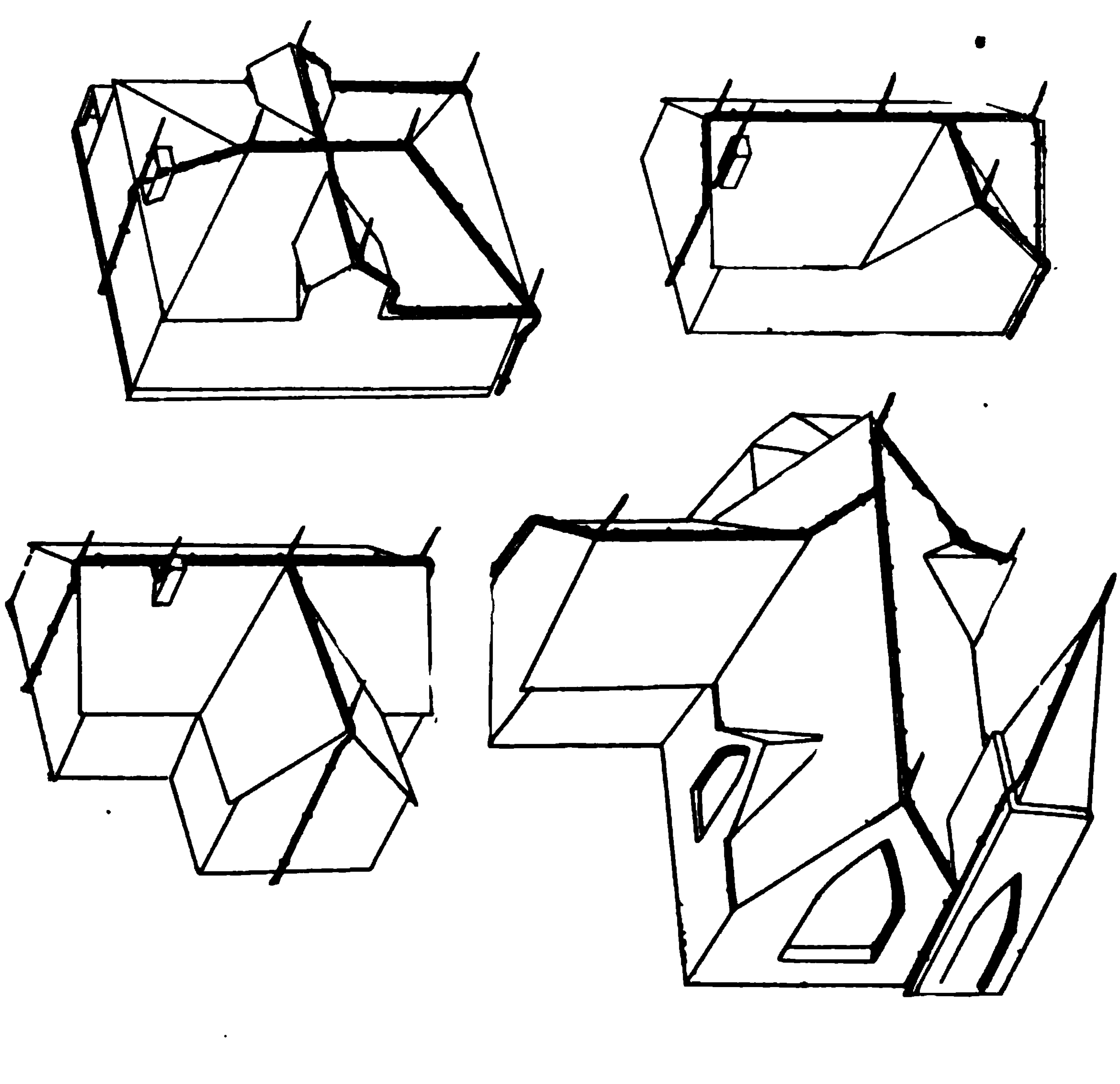


Fig. 7. Arrangements of Rods.

most exposed points in such a manner that from whatever angle a cloud should approach, the point on the building nearest the cloud would be covered by a conductor. It is also aimed to so connect the rods together that the lightning can find several paths to the ground at the same time; to get the verticals that lead to the ground well separated, and to have the paths to the ground as direct as possible There are three factors which may make it necessary to modify any scheme of conductors:

1. All rods must be kept well away from gas pipes, especially

if the gas pipes are of lead.

2. Rain spouts or other conductors may take the place of some part of the lightning conductor system.

3. It may be necessary to arrange the conductors a little differently in order to reach and connect to other metal work on the roof.

Rodding a Tree.—Where a house is overtopped by a large tree, the rod may be placed on the tree instead of on the house. The rod in this case must be of as good material and just as carefully grounded as if it were on the house. It should run out one of the limbs that reaches over the house, but should be kept clear of the house by as much as ten feet if possible. The rod should not be attached too tightly to the tree, and should have a little slack, to allow for growth in the tree.

The Ground Connection.—The entire rod may be rendered useless by a poor ground connection, and for this reason great care should be taken with this important part of the system. The elec-

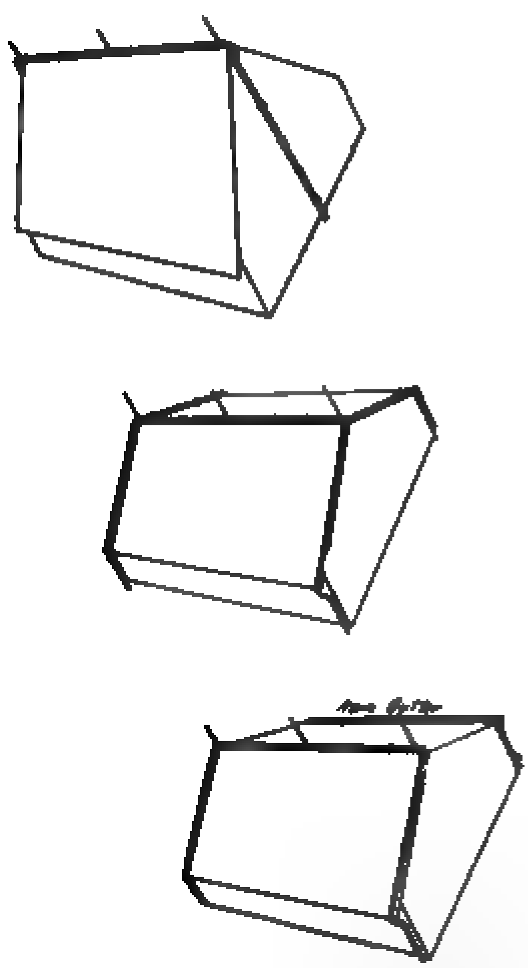


Fig. 8. A steep roofed building needs no conductors at the eaves. If the roof is flat, the eaves need protection, especially at the corners. The rain gutters may be sufficient protection for the eaves.

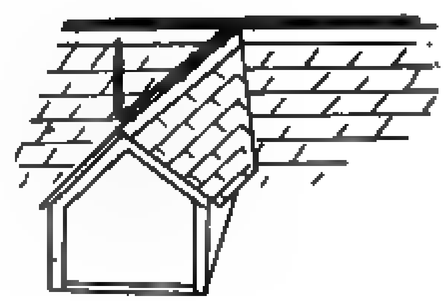


Fig. 9. If the ridge of a dormer or wing is short, and on the same level as the main ridge, it may be taken care of by a branch from the main line of conductor, as shown in the upper figure. But if it is below the level of the main ridge, or is more than about twelve feet long, a more direct path to the ground should be provided.

tricity must get to the ground water, or at least to wet soil. It can pass through moist soil, although this is a very poor conductor; but dry soil is such a good insulator that a lightning stroke on one occasion was known to travel 900 feet along a water pipe that was buried in dry soil, without being able to get away into the ground. The lightning reached the pipe in a house that was struck, went along the water pipe and did some damage to a drinking fountain 900 feet away.

You can not safely trust to luck that the ground will be moist four feet down. You must know from having dug down until you reached damp earth, and this ought to be done after a considerable period of dry weather. If you do not wish to wait for dry weather, and do not know what depth is necessary from previous observation, you should go deep enought to be on the safe side. In most places seven feet ought to be enough.

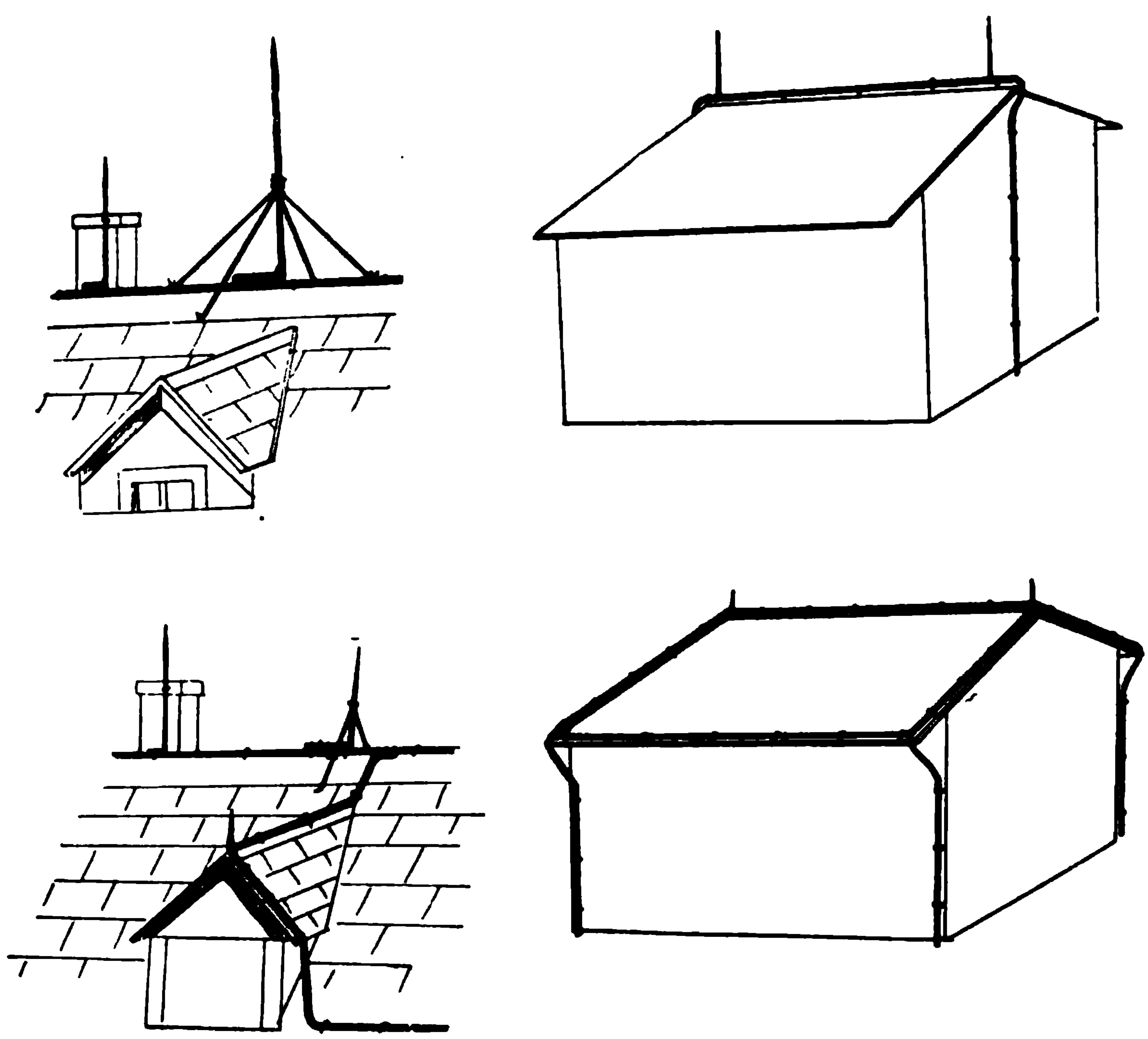


Fig. 10. It is largely a matter of choice and of appearance whether to use tall terminal rods, or to run extra lines of conductor to neighboring points that are somewhat exposed. But it is not well to rely on other near by rods to protect a chimney that is in use during warm weather.

Next in importance to reaching permanently moist earth is the problem of arranging the conductor so that the surface presented to the soil will be sufficient to allow the discharge to get away easily. The amount of surface of metal in contact with the soil is not the only thing to look out for. The electricity from the conductor must be able to spread out quickly into the soil. For instance there is no value in obtaining a large surface by burying a number of plates close together. The current flowing from one part of the conductor must not crowd the current coming from another part or from another conductor. For this reason two rods driven into the ground a foot apart are very much better than if driven six inches apart. A hole 18" square filled with coke is a very good ground connection, much better than that made by driving a 1½" galvanized iron pipe into the ground to the same depth; but two such pipes driven three feet apart and connected at the top are nearly as good as the hole full

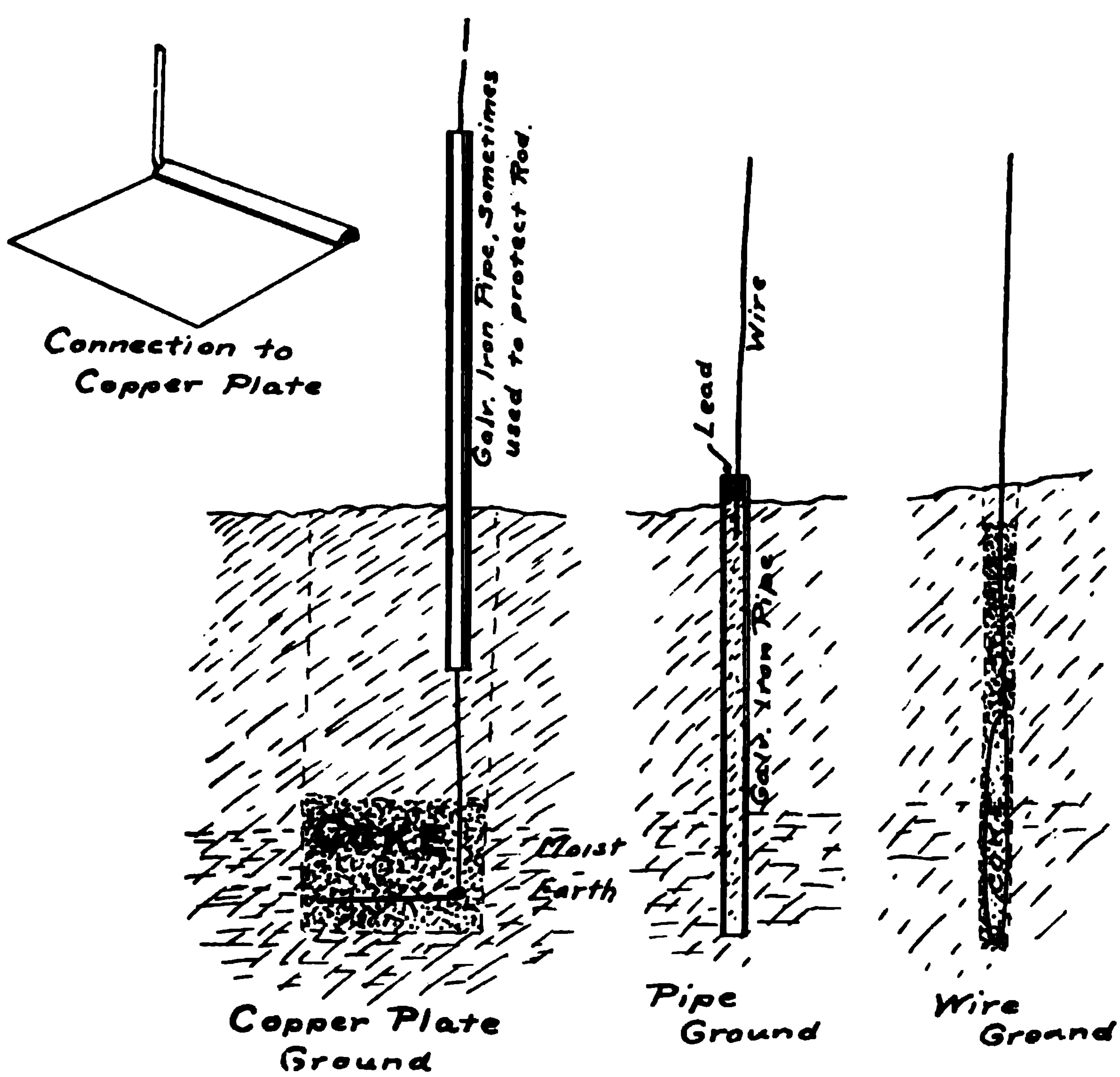


Fig. 11. Ground Connections.

of coke. Likewise the pipe is better than a wire 1-8 inch thick buried to the same depth; but two such wires six inches apart are as good as one pipe, although their actual surface is less.

All three kinds of ground connections have their places. The carefully made coke and copper plate ground is the safest and most permanent, and all large and important buildings should have at least one and preferably two ground connections of this kind or else a good connection to a water pipe. The other conductors on the same building may run to pipe grounds or to wire grounds.

Water Pipe Grounds.—This is the best of all ground connections and should always be used where there is a water pipe running to the building. A metal pipe from a well is as good as any water pipe if it is buried in the ground for some distance, but if it runs straight down the well without giving the lightning a chance to escape before it reaches the water, the well pipe should not be used.

Buried Plate.—Dig a hole 18 inches square and deep enough to get at least two feet below permanently moist earth. The wire that forms the lightning rod should be bent at right angles about 17 inches from the end. Cut a piece of sheet copper 17x18 inches and bend the edge over the wire so as to grip it tightly. The joint can then be heated with a blow-torch and solder run in. It would be well to use sheet copper as heavy as No. 22 gage, weighing about 14 oz. to the square foot for this purpose. Get about two bushels of charcoal or coke (the charcoal is preferable) and crush it sufficiently so that the powder and small lumps will fill up the spaces between the large lumps. Make a thin bed of the charcoal under the plate and put the rest on top. Pack the charcoal hard, and fill up the hole.

Instead of using a copper plate the wire itself may be coiled so as to present a large surface to the charcoal. The cost of such a ground should be about as follows:

Portion of rod below ground	$ .25
Copper plate	.50
Coke or charcoal	.25
Labor ..(Depends much on kind of soil and depth)..	1.00
	$2.00

Pipe Grounds.—Pipe grounds are neither as permanent nor as reliable as grounds made by burying copper plates in coke, but are sufficiently good for less important buildings or for some of the rods on a large building, if the most important rods of the building are furnished with copper plate grounds. By "most important" we mean the rods that come directly from the most exposed parts of the building.

Except in stony soil, one inch, to one and one-half inch galvanized iron pipe can usually be driven seven feet into the ground without great difficulty. If the soil is very sticky it may be easier to start the hole by driving a large pipe say three feet and then pulling it, and driving the smaller pipe the rest of the way.

To make the connection with the rod, insert the wire or rod a few inches into the top of the pipe. Fill the pipe with earth up to within an inch of the top and pour in melted solder or lead around the wire till it is flush with the top.

Care must be taken to protect the wire and place it where it will be secure from injury. It might in some cases be advisable to dig a hole and drive the pipe down until its top is a foot below the surface of the ground. The wire can then be run horizontally toward the wall and brought out of the ground right against the building where it will be secure. If there is any danger of any one's digging around it, the wire underground should be covered with a little concrete.

Pipe grounds ordinarily are very easy to make, but should not be relied on for more than about 10 years. The pipe will cost from 10 cents to fifteen cents a foot. On the average the cost might be:—

7 feet of pipe at 12cts.	$ .84
Labor	.30
Lead or solder	.05
	$1.19

Wire Grounds.—If a post hole auger is available or if the soil is such that a pipe can easily be driven and pulled out leaving a clean hole, wire grounds are the cheapest thing that can be used, and if carefully made should be nearly as good as pipe grounds. Since a good piece of copper wire as large as No. 6 B. & S. will last underground indefinitely, it is in this respect better than the galvanized pipe. The wire should be bent back to form a loop about 2½ feet long, the end being wrapped a few times around the main wire. Make the loop narrow enough to enter the hole easily, and be sure that it reaches the bottom. Fill in around the wire with powdered coke or charcoal and ram it down tight.

A ground of this kind will do for the less important rods on a large building or for any rod on a small building. It should cost not more than about 25 cents for the copper in the buried conductor (if No. 4 B. & S. wire is used) and about an hour's labor.

In Case of Rock.—In case a house is built where there is a ledge of rock a few feet below the surface of the ground, there is frequently some difficulty in getting a good ground connection. A water pipe

connection should be used if possible. If a deep seam in the rock can be found make a ground connection in this. If necessary run the wire some distance in a trench to get to a good place for a ground connection. If nothing but solid rock can be found, dig a trench down to rock and some twenty feet long for each rod. Run a wire in a three inch layer of crushed charcoal or coke the full length of the trench.

Grounds Made Before the House Is Built.—If it is decided that a new house is to be rodded, figure out where the ground connection will come, before the foundations are put in. Run a No. 4 or No. 6 wire buried in crushed charcoal six feet along side of the footing in the bottom of the foundation trench and bring the wire up either outside or right through the concrete or masonry. The wire may continue inside the building all the way up to the eaves if desired. or it may be enclosed in the wall or buried in brick or stone work

Points or Terminal Rods.—If the rods run all the way up to all the prominent points of a building it is not necessary that they project above in the form of points if there is any serious objection to the points on the ground of appearance. If the points are omitted, conductors should run along all ridges and eaves, and to the top of each chimney where they should be attached by running a wire all around the chimney as close to the top as possible.

On most buildings, however, lightning rod points are not objectionable in appearance, they may be even decorative, and their presence adds to the security of the building by still further reducing the chance that lightning may strike anything but the rod. Besides this the points assist in preventing a lightning stroke from occuring at all. There is some difference of opinion as to the advantage of placing a number of sharp points on one terminal rod. The silent discharge from two points would be twice as great as from one point, if they did not interfere with each other, but the effectiveness of a point depends on its projecting above, and being kept away from other conductors. Hence is is doubtful if the advantage of placing a number of points together on a single rod is sufficient to justify the extra labor or expense.

The pointed terminal rods are ordinarily made from two to four feet high, and should be placed on all prominent points of the building and every 20 feet on long ridges. They should be made of copper and filed to a sharp point at the end. No. 3 B. & S. wire should be brought to a point in about 3-4 inch, No. 0 wire in 1 inch, and No. 0000 gage wire in 1 1-4 inches. The terminal rod needs to be of heavier material than the main conductor, first to secure stiffness, and secondly because it is more likely to be the part actually

struck and hence is in more danger of being melted. "Hard drawn" wire should be obtained if possible for terminal rods since it is stiffer than the soft drawn, but the soft drawn wire is better for the main conductors. No. 2 or No. 3 wire may be used where it does not project more than ten or twelve inches above the last support. It might be used on such places as flag poles and chimneys.

No. 0 wire can be used where the rod does not project more

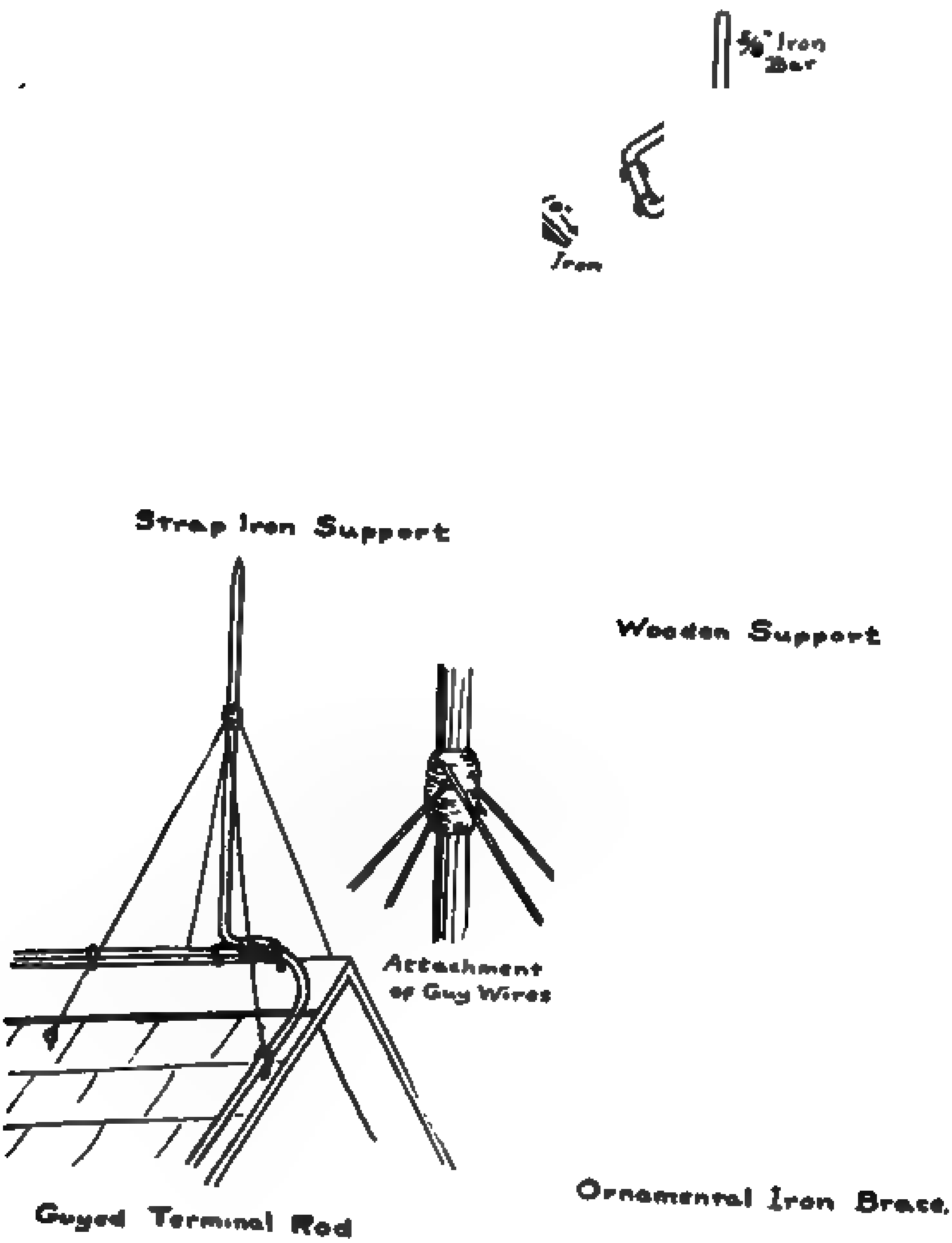


Fig. 12. Supports for Terminal Rods.

than 18 inches, and No. 0000 is stiff enough to stand about 24 inches above the last support.

Supports for Terminal Rods.—Several forms of supports are shown in Fig. 12. The strap iron support can be made up at a blacksmith shop and fastened to the roof with lag screws, care being taken to locate it directly over the rafters. It would be strong enough to support a rod four feet high.

The rod may be supported by wooden bracing. The only objection to the wooden support is the difficulty of giving it a good appearance.

If the terminal rod is fastened well at the bottom and braced by four guy wires, no further supports are necessary. A few small notches are filed in the rod about a foot from the top, or a small hole may be drilled and a pin put through. Two wires are wrapped tightly around the rod, above the pin or in the notches, leaving four ends three to five feet long as may be needed. No. 12 wire is a good size for the guy wires. The joint at the rod should be made more secure by wrapping a few turns of small wire on the outside, twisting the ends together and filling the whole joint with solder. The lower ends of the guy wires may be fastened with staples or screw eyes in the roof. This is probably the cheapest and strongest way of bracing terminal rods, especially the taller ones. The rod needs to be set back about a foot from the gable end if it is to be braced by guy wires. No. 0 wire would be heavy enough for rods braced in this way. Supports made especially for lightning rod terminals can be bought from dealers at a reasonable figure.

The Main Conductors.—The rods running from the terminals or points to the ground connections may be fastened to the building with large galvanized iron staples or with screw eyes. There is no object in insulating the rod from the building with glass or porcelain. There should be a fastening at every two and a half feet, on horizontal runs and every four feet on vertical runs. It is possible that a heavy lightning discharge might heat a small rod hot enough to set fire to woodwork. For this reason it is recommended that the rod be kept clear of wood in places where the wood is likely to be very dry and where a fire might gain considerable headway before being discovered. On the outside of the building, however, it is not usually considered necessary to keep the conductor away from the woodwork, since a fire from this source is very unlikely, and would probably be extinguished by rain if it should start.

If, however, the owner wishes to take every possible precaution, it is suggested either that he use a heavier conductor (say No. 2 or No. 3 B. & S. Copper wire) or else that he use some form of support

which will hold the wire out from the wood work by about an inch, and that he place the supports not more than two feet apart. A few examples of suitable supports for this purpose are the double staple, porcelain cleat, and the screw eye.

Where appearance is not of prime importance, fasten the rod to woodwork with staples. Drive two staples side by side, one to hold the wire out from the building, and the other to fasten the wire, as shown in Fig. 13. The wire passes outside the first staple but under the second.

Porcelain cleats, such as are used for inside electric wiring, make very neat and satisfactory supports, but are more expensive

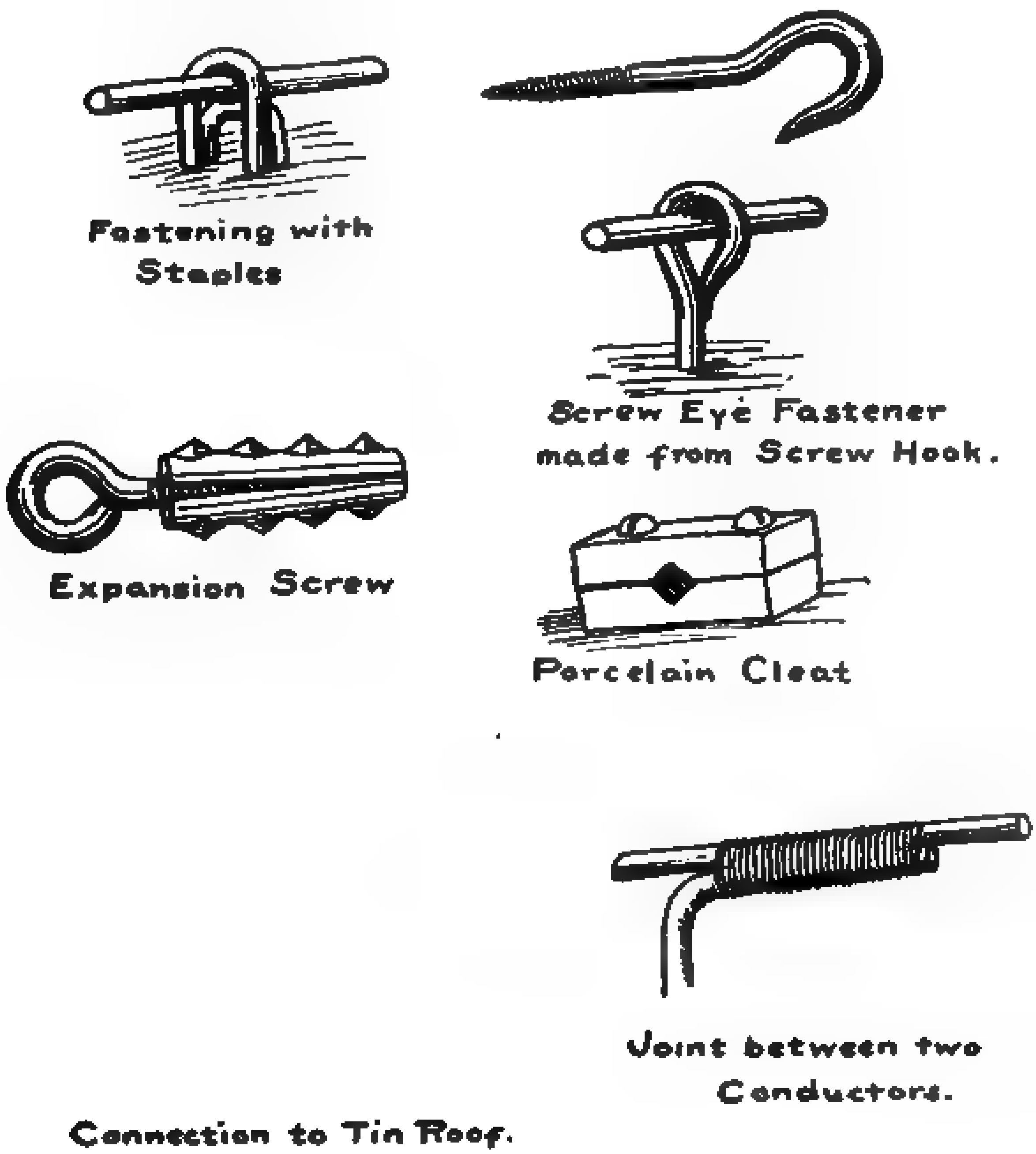


Fig. 13. Methods of attaching conductors to buildings.

than the other supports mentioned, costing in the neighborhood of $2.00 per hundred without screws.

Screw eyes are about as satisfactory in appearance as any support. Instead of buying screw eyes however, get No. 8 screw hooks (preferably brass) screw them in place, slip the wire under the hook and bend the hook shut around the wire. If regular screw-eyes are used they will either have to be screwed in place and the wire threaded through, which is likely to be difficult, or else the eyes may be bent open before putting them in place. Then the eye can be bent shut again around the wire as in the case of the screw-hook. Besides saving part of this labor, the screw-hooks have the advantage that they are made with longer shanks than the screw-eyes

Expansion eye-bolts are useful in fastening to brick or stone.

Rods may be run inside the building, or concealed in the wall if there is any good reason for doing so. The objection to enclosing them in a wall is that they are not open for inspection, and that a fire (if by any possibility one should be started) would not be discovered as promptly as if the rod were in the open. On the other hand the rod is protected from theft and from mechanical injury by enclosing it. The above objections do not apply to stone, brick or concrete walls. If a rod is to be placed within a wooden wall, it should be wrapped well with asbestos paper, and the paper securely fastened in place with wire, wherever the rod passes through a board, or where there is any possibility of its coming in contact with any wood. Here again the necessity of keeping the rod from touching wood, depends on the size of the conductor, but instead of using a large conductor for such places as inside a wall, where the rod is concealed, run an extra No. 4 conductor, parallel with the main line and wrapped about it at both ends, so that if either wire should be broken or cut the other would serve the purpose. The spare wire should be attached to the main conductor below ground, and should reach up above the place where the rod is concealed, and connected in again there. Another good arrangement is to box in the space where the rod is and fill up the form with concrete or else with dry sand.

It is usually necessary to take some care to protect a rod from theft. The copper is of some value, and the part of the rod near the ground is very easily cut and carried away. Painting the rod will help by making it less conspicuous. On stone or brick buildings it may be partly concealed by vines. The copper-clad wire, described later, has the advantage that it is very tough, and that its value as junk is almost nothing. The most common way of protecting copper rods from thieves, is to enclose the rod in a galvanized iron

pipe reaching about two feet below ground and eight feet above. The pipe must be securely fastened to the building. Another way is to wrap the rod with asbestos paper and nail a grooved plank over it, running a spare wire alongside as described above. The rod may be run inside the wall, or a small form may be built around it and filled with concrete, first driving a number of stout nails or screws into the wall for the concrete to hold to.

In arranging the conductors avoid all sharp bends. Use long easy curves or "goose-necks" in going over the eaves, but if the overhang is considerable it is better to bore a hole and go straight through close to the wall. No joints should be used if they can possibly be avoided. The house should be measured before the material is ordered, and the order should give the lengths required, adding a few feet for good measure. Let the Supply House do the cutting if possible. Fasten the copper plate to one end of the wire and bury it in charcoal as already described. Without cutting the wire arrange it over the building as it is to go, and make the ground connection on the other end. Thus a single conductor should run from the buried copper plate at one corner of the building, up to the eaves, to the ridge, along the ridge to the other end and down to the other buried plate, without a single joint or splice.

Joints.—Where connection is made between two lines or rodding the joint should be made by wrapping the two together with smaller copper wire (say No. 19) and filling the cracks with solder. Be sure that all wires are clean and free from grease before attempting to solder. Treat the surface with acid used by tinners.

Material for Rods.—We have so far spoken of the conductors as "wire." Solid wire is about the cheapest form in which conductors can be had, and is easy to handle, and for this reason is the material usually preferred for home-made rods. There are other forms of conductors on the market, however, which are worthy of notice and which will be mentioned here.

The following table shows the sizes, weights and cost of a few sizes of wire that might be used.

Material.	Size B. & S. Gage.	Diameter Inches.	Weight per 100 ft.	Cost per Pound.	Cost per 100 ft.
Solid	19	.035	0.4	25c	$ .10
Copper	12	.081	2.0	22	.44
Wire	10	.102	3.1	22	.68
	8	.128	5.0	20	1.00
	6	.162	7.9	20	1.58
	4	.204	12.6	20	2.52
	3	.229	15.9	20	3.18
	2	.257	20.1	20	4.02
	1	.289	25.3	20	5.06
	0	.325	32	20	6.40
	00	.365	40.2	20	8.04
	000	.41	50.8	20	10.16
	0000	.46	64.0	20	12.80
Aluminum	10	.102	1.0	45c	.45
Wire	8	.128	1.5	45	.68
	6	.162	2.4	45	1.08
	4	.204	3.8	45	1.71
	2	.257	6.1	45	2.75
	4	.325	9.7	45	4.36
	0000	.46	19.4	45	8.75
Copper	10	.102	2.9	16c	$ .46
Clad	8	.128	4.5	16	.72
Steel	6	.162	7.2	16	1.15
Wire	4	.204	11.5	16	1.84
30% Conductivity	2	.255	18.5	16	2.95
	0	.325	29.2	16	4.68
Galvanized	Birmingham Gage No.				
Iron.	12	.105	3.1	5c	.15½
Wire	10	.135	4.9	5	.24½
E. B. B.	8	.162	7.2	5	.36
	6	.192	10.2	5	.51
	4	.225	13.8	5	.69
	3	.244	16.3	5	.82
	2	.263	18.9	5	.95

The above prices are approximate only, but will serve as a guide and to help in deciding what material to use. Copper changes considerably in price from month to month. Costs on special forms of lightning conductors will have to be obtained directly from the manufacturers.

Size of Conductor.—It has been the custom to use heavy copper conductors in order to avoid danger of their being melted, and also to reduce the danger of side flashes. The value of large conductors in respect to the latter point has been overestimated. The danger of melting and the mechanical strength of the rod are the principal points to consider. Records of melted rods are so few that it is impossible to say just what is the smallest size that will carry off a fairly heavy lightning discharge. No ordinary rod can be depended on not to melt at the point where it is struck, for the heat developed where the lightning passes from the air into the rod is very much

greater than the heat developed in the rod itself. It seems probable that a No. 8 copper wire will conduct any ordinary lightning discharge without melting in two. This much is certain, even if a conductor should melt, it would have done its work before melting, so far as that stroke was concerned. As long as the conductor is there the lightning will pass through it. By the time it is melted a path is already formed and the electricity would continue to flow over the same course. There are cases on record of wires that directed strokes in this way, although the wires themselves had disappeared. This does not mean that it is well to employ a conductor that will melt, but it goes to show that even a conductor which melted during a heavy stroke would be better than none.

There are four ways in which too small a conductor is dangerous:

1. If it melts it may possibly cause the stroke to seek some other course which it would not if the rod had remained intact.

2. The great heat developed where the rod melted in two would increase the danger of fire.

3. If a second stroke should occur during the same storm, the house would be unprotected.

4. If the melting should not be noticed and the rod not repaired, the house would be unprotected in future storms.

It seems advisable to keep on the safe side by using conductors considerably heavier than that which is thought to be just sufficient not to melt.

In the arrangements of rods recommended in this bulletin there are (except for short distances) always two or three paths for lightning to get to ground. With such an arrangement it is believed that No. 6 copper wire would be safe, but in order to take no chances No. 4 is recommended for all the rods running to the most exposed parts of the building, while No. 6 might be used for cross connections and for conductors on places that are less in danger, such as eaves. It will be seen by consulting the table that the cost of No. 4 is only about $1.00 more per 100 feet than No. 6, and the amount saved by using the smaller wire for the main lines of conductor is not enough to make it wise to economize in this way.

If other copper conductor than the wire is used it should have at least as much weight per foot as the wire recommended here.

Other Materials for Rods.—Copper lightning rods have been made in many different shapes, such as square bar, fluted and twisted rods, flat strip, stranded cable, round woven cable, and flat woven cable. These forms have some advantages, but usually increase the cost more than they increase the efficiency of the rod.

There is no special virtue in any particular form of rod. Lightning does not travel better in a spiral. The only laws that

lightning follows that have any thing to do with the shape of the conductor, are the laws that have been already stated in regard to the tendency to concentrate at the surface or edges or corners of a conductor. (See Page 19). The only purpose in making a rod any other shape than round, is to economize copper, and perhaps to make a conductor that is more easily installed.

A comparison will be made between a copper wire rod and some of the other forms, assuming that they all contain the same amount of copper per foot. Flat copper strip can be obtained from some electric companies and wire manufacturers.. It offers somewhat less resistance to the electric current than a round wire of the same weight, but is no better in this respect than two smaller wires placed an inch or two apart running parallel. The strip is somewhat more easily damaged than the round wire, and is awkward to install in some places.

Square or fluted rods, twisted or plain, have very slight advantage over round wire, and are hard to make good connections and joints with.

Copper wire rope or cable is somewhat easier to handle in larger sizes than solid bars of the same weight. For sizes less than No. 0 this advantage does not amount to much as the bar is not very stiff. Conductors made up of small strands are probably somewhat more easily melted than solid bars of the same weight. The theory that the extra surface exposed to the air will help keep the cables cool would be correct if the heating were slow and continued, but when it is all over in less than a second the circulating air has not time to do much good.

Woven copper cable both in the round form and flat, are made expressly for lightning conductors. They have no very great advantage electrically over other forms, but they are easily handled, and lend themselves readily to making joints, where joints are necessary.

Copper Clad Steel Wire.—A wire is made for some electrical purposes consisting of a steel wire with a covering of copper. A heavy copper tube is placed over a steel bar and the two welded together, rolled and drawn out info wire. This results in a wire with a very much thicker coat of copper than would be given by plating the steel with copper. It is made with various proportions of copper and steel. The kind known as "30 per cent Conductivity" is suitable for lightning conductors, and may be used in place of the solid copper wire for the larger sizes. For sizes less than No. 4 the saving is not enough to make it worth while. Since all the current flows close to the surface of the lightning rod a No. 4 copper clad wire will carry it as easily as a No. 4 solid wire. The copper clad

wire costs four-fifths as much as the solid coppei wire of the same size. It is very stiff, but this is not a serious objection, as sharp bends are always to be avoided. The principal objection to this material is the possibility ot the copper covering being injured and the steel rusted through. It is doubtful whether it would last as well underground as solid wire, but above ground it should prove as durable as the solid. It will not do for terminal rods or points. In buying copper clad wire care must be taken to distinguish it from copper plated wire which is much cheaper and not suitable for this purpose. The copper clad will be seen by cutting to have a substantial covering of copper amounting to about one-sixth of the total amount of metal in the wire.

The following companies handling copper clad wire have come to the writer's attention:

Duplex Metals Co., Chester, Pa.

J. A. Roebling's Sons, Trenton, N. J.

Western Electric Co., Chicago, Ill.

Standard Underground Cable Co., Pittsburg, Pa.

Aluminum.—Aluminum wire can be obtained from companies handling wire for electrical purposes. An aluminum rod needs to be two or three sizes larger B. & S. gage than a copper wire for the same purpose. There will be little difference in the cost, and there is little choice between the two materials. Solder can not be used on aluminum, but merely placing the wires together and wrapping well with small aluminum wire results in a very good joint. Aluminum will last as long as copper, whether underground or over head, except near salt water, where it corrodes. Aluminum may be used to advantage for terminal rods instead of copper, since the same sized wire is lighter and just as stiff and costs less. There would be little economy in using aluminum points with copper rods, unless the same company handled both kinds of wire, as the extra freight or express would probably cost more than the saving.

Galvanized Iron Wire.—This is the cheapest material that can be used for lightning rods and is fairly satisfactory while it lasts. The best grades on the market (known as E. B. B. double galvanized) should be used. It would be well to use somewhat larger sizes than are required for copper rods, say No. 2 B. W. G. for the more important lines and No. 4 for the less important. Although more heat is developed in an iron rod than in copper, the iron is much harder to melt, so in this respect it is about as safe as the copper. The objection to galvanized iron conductors is that they will not last as well as the copper. Near railroads or factories or near the sea galvanized iron wire lasts but a short time, but in the inland where the air is pure it should last from 15 to 25 years. If used for terminal rods

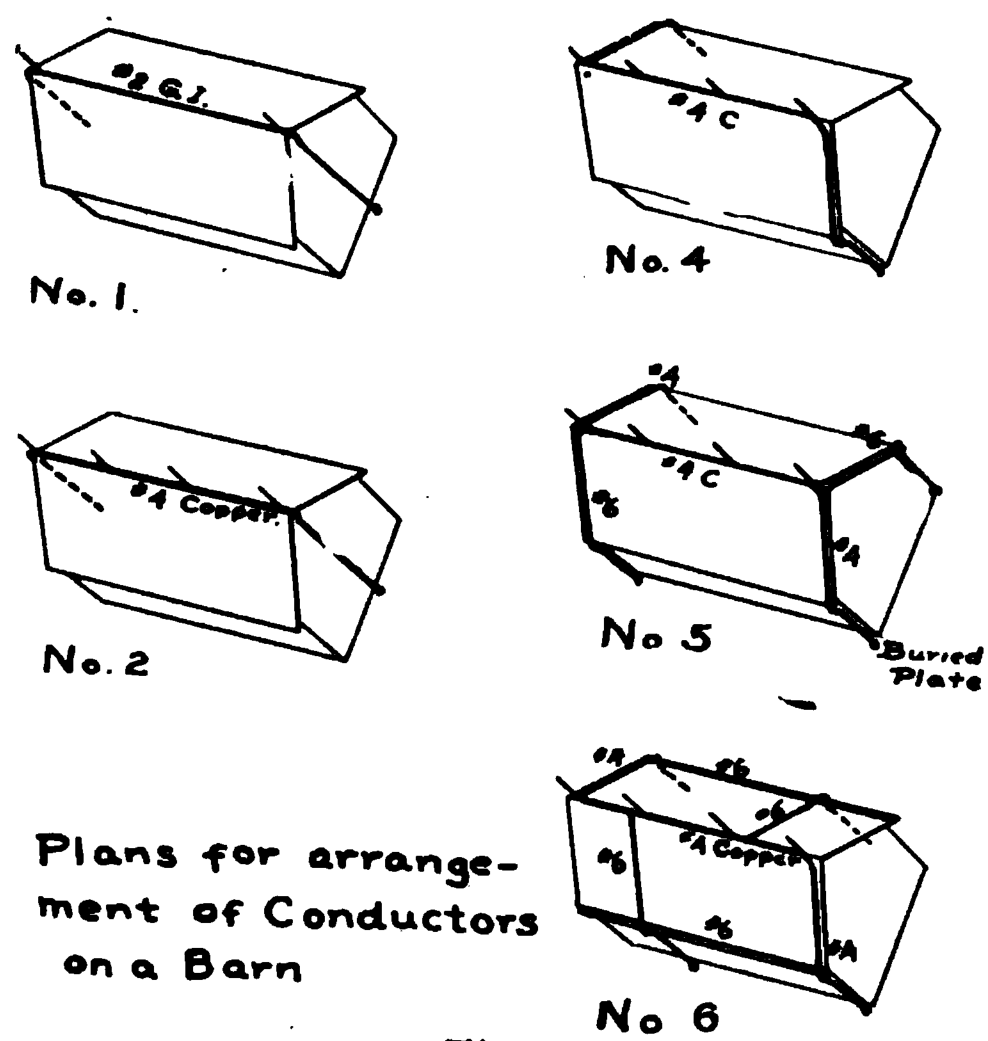


Fig. 14.

the points will rust blunt before a great while, and for this reason some other material is to be preferred. A short piece of copper wire, pointed, may be attached to the end of the galvanized iron terminal rod. The iron wire cannot be trusted underground for any length of time, hence pipe grounds would naturally be used in connection with iron rods, or else the iron wire may be joined to a copper or aluminum wire just above the surface of the ground. Joints should be made by wrapping with small copper wire and soldering.

Galvanized iron rods should be kept well painted.

Cost of Rodding a Barn.—In order to compare the different possible ways of rodding a building we shall take as an example a simple barn forty feet wide, sixty feet long, height of ridge above ground forty feet, height of eaves above ground twenty feet, distance from eaves to ıidge twenty-nine feet.

The simpler arrangements outlined below will give fair protection, while the more elaborate arrangements will give greater security. For example, while plans No. 1 and No. 2 might reduce the danger from lightning to something like one-tenth part of what it would be without rods, plans Nos. 6, 7 and 8 would reduce the chance of damage to perhaps one-fiftieth part of what it was before.

Plan No. 1. Iron rod along the ridge only. Two points.

150 feet of No. 2 B. W. G. galvanized iron wire	$1.50
2 galvanized iron pipe ground connections	2.40
2 terminal rods with supports	2.00
Labor—placing conductor on barn	1.50
	$7.40

Plan No. 2. Same arrangement, but using No. 4 copper wire. One buried plate ground and one wire ground connection.

165 feet of No. 4 copper wire	$ 4.20
2 terminal rods with supports	2.00
1 buried plate ground	2.00
1 wire ground	.50
Labor—¾ day	1.50
	$10.20

Plan No. 3. Same as No. 2, but with four terminal rods......$12.20

Plan No. 4. Same as No. 3, but rods running over to the corners of the barn instead of straight down from the ridge. See illustration, Fig. 14.

This arrangement is frequently made necessary by doors in the ends of the building that interfere with running the rod down the face of the end wall. If the roof has less pitch than that given here (rise equal to one-half the span) plan No. 5 is decidedly recommended in place of No. 4. In any case No. 5 will give better protection. No. 4 exceeds the cost of No. 3 by 18 feet of No. 4 copper wire, costing 45 cents.

Plan No. 5. Rods running from the ridge to all four corners. No. 4 wire running all the way from one corner to the opposite corner. Branches to the other corners of No. 6 copper wire. Four terminal rods on ridge. One buried plate ground. Three wire grounds.

185 feet of No. 4 copper wire	$ 4.68
115 feet of No. 6 copper wire	1.82
4 terminal rods	4.00
1 copper plate ground connection	2.00
3 wire ground connections	1.50
Labor—placing conductor on building	3.00
	$17.00

Plan No. 6 same as No. 5, but a line of No. 6 copper wire run along the eaves of the roof.

120 feet of No. 6 wire	$ 1.90
Extra labor	.50
Other items as in No. 5	17.00
	$19.40

It would be well to run the lines of No. 6 wire that lead from the ridge to the ground about 15 feet back from the ends of the roof, thus providing a shorter path to ground for a lightning discharge that strikes the ridge near the middle.

This plan is advisable for a building with less pitch to the roof than the one described here. For buildings longer than 60 feet extra rods from the ground to the ridge should be placed on the side of the building.

Plan No. 7. Same as No. 6, but using two buried plate grounds at opposite corners and two wire ground connections. Estimated cost, $21.00.

Plan No. 8. Same as No. 6, but using three pipe grounds and one buried plate ground, and No. 2 and No. 4 galvanized iron conductor.

185 feet of No. 2 galvanized iron wire	$ 1.75
235 feet of No. 4 galvanized iron wire	1.65
4 terminal rods	4.00
1 buried plate ground connection	2.00
3 pipe ground connections	3.60
Labor—placing conductor on building	3.50
	$16.50

About $5.00 is saved by using iron instead of copper on a barn of this size covered with conductors as described in Plans Nos. 6, 7 and 8.

In addition to the materials named above, there would be required a half pound of No. 19 copper wire, one to three pounds of solder, some tinner's acid, some staples or screw hooks, coke or charcoal and copper plate, or galvanized iron pipe with some extra lead or solder for the ground connections.

The tools needed would be a post hole scoop or auger, gasoline torch, file or hacksaw, large pliers, sledge hammer or mallet for driving pipe, and carpenter's hammer.

Contract With Lightning Rod Companies.—As compared with the systems of rods installed by the owner, there are advantages in turning the job over to a company making a specialty of lightning rods. The completed work will very likely have a much more pleasing appearance if done by a lightning rod firm.

In the matter of safety, it would be money well invested to pay for expert advice, but it should be remembered that the real skill and knowledge is required, not for deciding what form of conductor or point to use, but in arranging the conductors on the buildings to secure the best protection with least expense, and in judging as to what depth and kind of ground connection is necessary.

The advantages of various forms of conductors have been discussed in this bulletin and there is little else to be said on this subject.

It is very difficult on the other hand to lay down rules as to the best places to run the rods and how to take care of other metal work in the house, because the conditions are different in every case. Each building is a problem by itself. It is here that trained judgment is valuable.

There are two ways a lightning rod company may furnish expert knowledge to its customers.

1. It may employ a man to devote his entire attention to this business, to visit the places of prospective customers, find all about the local conditions and lay out the plans for rodding.

The trouble with this plan is that the customer can not always tell whether the visitor is a real expert or not.

2. The company may give the agency for its rods to a local hardware dealer, tinner or plumber, requiring the local agent to send to the company complete plans and sketches of the building, showing the location of all metal work in or on the building, and notes on the character and moisture of the soil. With this information at their command, the company is in a position to give intelligent advice and can submit its plans and estimates to the customer. With any less information than this, any claim to giving expert advice is a mere pretense.

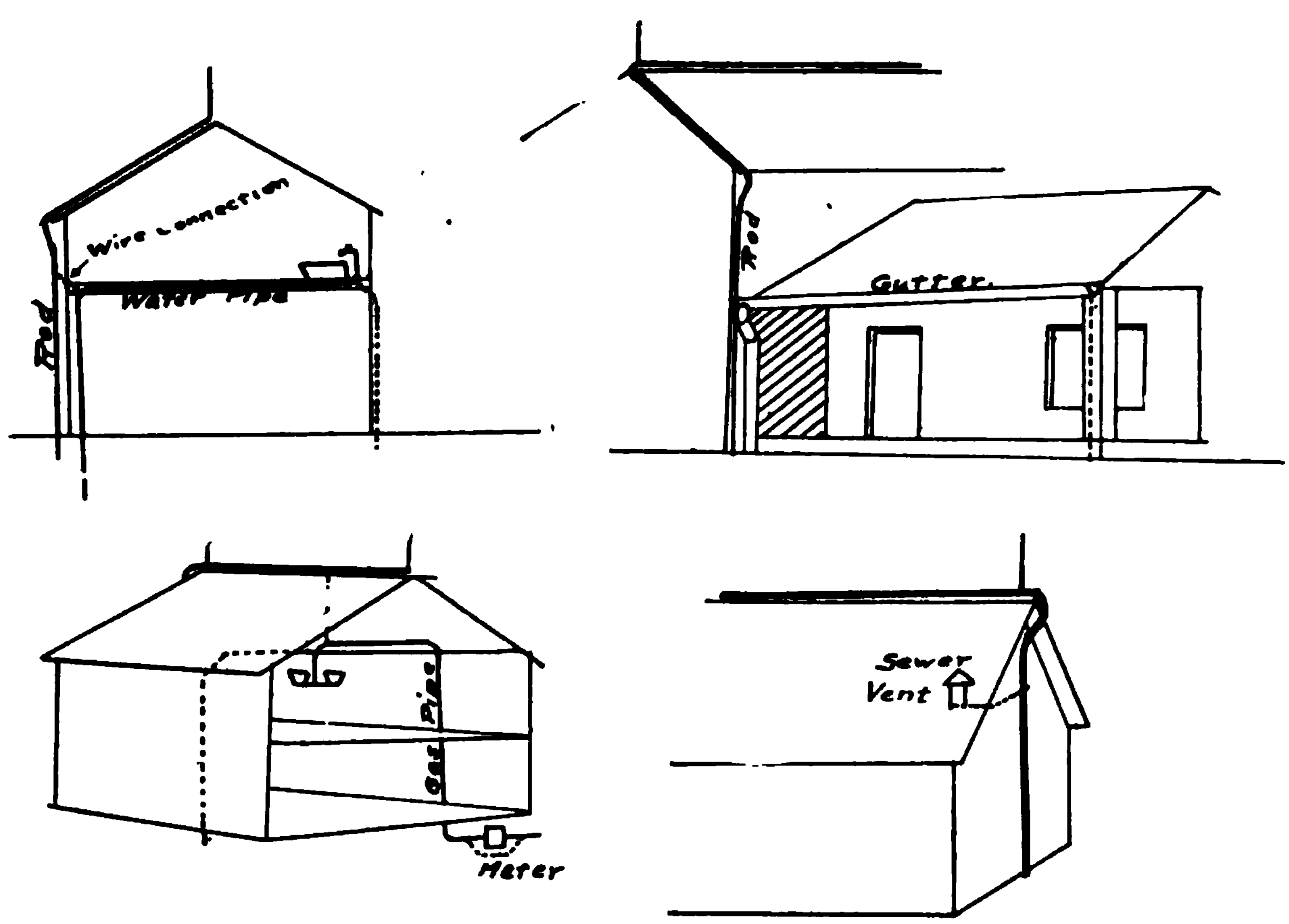


Fig. 15. Examples of situations where metal work in or on the building may become dangerous. The connections necessary to make it safe are shown in dotted lines.

Connections to Metal Work in the Building.—Large pieces of metal work about the house are likely to be a source of some danger in two ways. They may be actually struck and form part of the path that the lightning discharge uses in getting to ground, or they may be made dangerous simply by the influence of the other nearby conductors that are carrying off the discharge. This second effect is likely to occur in long conductors, such as water pipes, or rain gutters, especially when one end is near to or runs parallel with one of the rods and the other end projects away from the rod. Sparks may occur at the end of the conductor t' at is farthest from the rod.

It may be well to discuss briefly some of the commonest kinds of metal work about a house.

Metal on the Roof.—As has already been stated, all tin roofing, metal flashing or lining on ridges or in valleys, all ventilators, weather-vanes and ornamental iron work should be connected to conductors leading to the ground and the connection should be at the lower edge or end of each piece.

Gutters and Rain Spouts.—These are usually so located that they can be made to form a valuable part of the system of protecting

Fig. 16. Rain gutters serve to tie the different rods together, and also to protect the eaves where they are not very much exposed

conductors, but in using them in this way three points must be kept in mind.

1. They should not be the sole protection except for less exposed points. On flat roofed buildings where the gutters run to the points that are in most danger, they should be connected to the ground by rods at the corners, placing no reliance on the rain spouts.

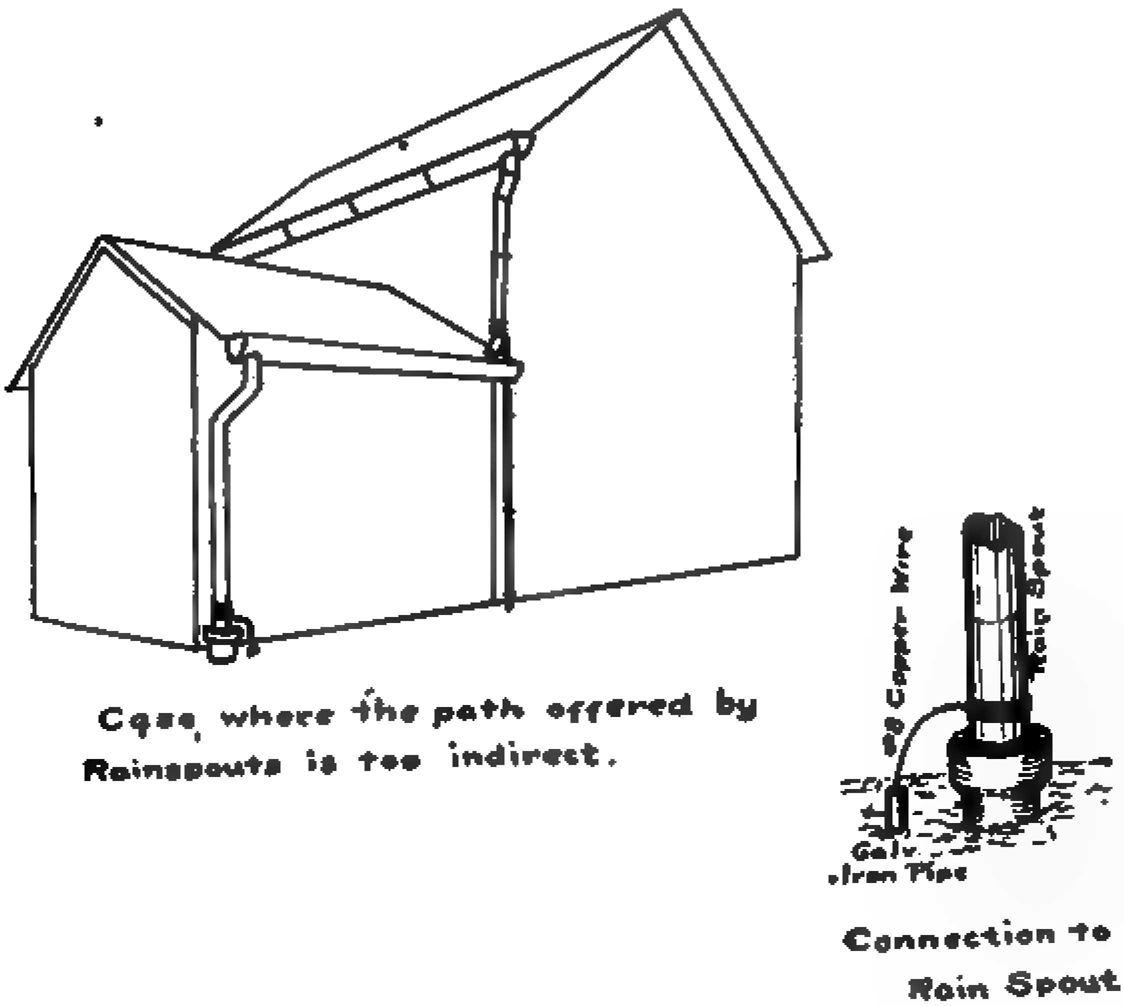


Fig. 17. If a rod passes near one corner of a tin roof, connect the two together and make a ground connection at the far corner.

The rain spouts, however, should be grounded. The gutters and rain spouts should be allowed to help out the rod in carrying off the discharge, but the rods should also be arranged so that they can help the rain spouts to carry it off. The reason for this is that the rain spouts frequently rust out before long and the joints are very poor electrically.

2. The path formed by the gutters and spouts is frequently too long and roundabout. In this case an extra connection should be made giving a more direct way for the lightning to reach the ground. See Fig. 17.

3. A good ground connection must be provided at the bottom of all rain spouts, whether they enter the earth or not. Spouts that are carried into the ground usually only reach a short way down, or else the rain water is carried off in tile pipes which are of non-conducting material.

Interior Metal Work.—Extensive piping inside the house greatly complicates the problem of lightning protection. There are two general methods of taking care of such piping:

1. Connect all ends of gas or water pipes either to the ground or to one of the lightning rods by means of stout wires. If any pipe or metal furnace flue passes within ten feet of a rod make a wire connection across between the two. At least one end of every pipe must be connected with the ground. Make ground connections to the furnace and to the kitchen stove. Figure 15 shows some of the cases where such connections are necessary. Special care must be taken of gas pipes, especially if they are of lead, keeping them well away from the rods if possible.

2. Interior piping may be rendered safe by making the system of conductors on the outside so complete that the lightning would have no tendency to make use of the conductors in the house. In order to do this, lines of conductors should be run along all hips and ridges, along all roof edges and eaves, and a vertical rod with a ground connection should be provided at each corner. At the same time the rods should all be kept at least ten feet away from any of the inside metal work

This second plan will ordinarily be easier to carry out, and is safer for any one who is not an expert.

Stoves.—Stoves, especially kitchen ranges that are in use during the summer, are objects of some danger in thunderstorms, and a connection with the ground should be made by means of a No. 10 or No. 8 copper wire. The wire may be soldered to the piece of sheet zinc or iron on which the stove rests, or attached to the stove by one of the bolts with which the legs are fastened. The wire may run directly to a pipe driven through the cellar floor or may pass

through the wall to a lightning rod outside.

Electric Wiring.—Electric wires can not be connected with the ground directly, as in the case of other metal work, but grounded wires may be run **near** the electric wires so that lightning will jump across at this point instead of somewhere else.

Properly equipped telephone sets are provided with "lightning arresters" and wires running to the ground.

Electric light wires are not always provided with any special arrangement to guard against lightning. It is well to observe the following precautions: If the wires are run through the building in iron pipes, the pipes should be connected with the ground. If the main switch that controls the supply of electricity to the house is in an iron box, the box should be connected with the ground. If this switch is not provided with an iron case, a grounded wire should be attached to the meter case.

Electric light wiring and fixtures, and also telephones, should be so placed in the house that it would be impossible to stand on a hot-air register or in a bath tub, or next to a washstand or sink or radiator, and at the same time reach an electric light switch or wire. This is a precaution not only against lightning, but also against danger resulting from accidents to the wires outside.

Sewer Vents.—It is common practice to run an iron ventilating pipe from the sewer up through the roof. If the sewer is as deep as five feet below the surface of the ground, and if it is of cast iron where it goes through the cellar wall, no attention is required. If the sewer is of tile pipe where it goes through the wall, a ground connection should be made for the vent pipe.

OTHER PROTECTIVE MEASURES.

Personal Safety.—The question where is the safest place to be during a thunderstorm must be answered in a general way. Do not stand near the **end** of any line of metal conductor that may become part of the path of a lightning discharge. Do not place yourself where you may become a link in a chain of conductors that may be used by the lightning. A conductor near by will increase your danger in one position and reduce it if you are in a slightly different position. The best rule is probably to keep away from all metal work that is of any size. Especially, do not stand between electric light fixtures or wires on the one side and plumbing, radiators or hot air registers on the other side. Small metal objects are of no consequence. Stoves may be dangerous during a storm. It it just as well not to use the telephone or turn electric light switches. Do

not sit or stand close to where a lightning rod runs down the outside of the building. A mental bedstead is an exception to the rule to keep away from large conductors, as the bedstead is shaped so that it very effectually protects the person in it.

The danger from open windows and doorways has probably been exaggerated, but it may be better to keep them closed unless they are covered with wire netting, in which case it makes no difference.

A person caught in a storm naturally seeks shelter from the rain, and frequently the nearest shelter is a tree. Many people have been killed by the tree's being struck, but with a little precaution there need be no more danger under a tree than elsewhere.

Do not select the tallest tree of a group.

Do not run to a single tree standing by itself, if it is possible to reach a place where there are several trees together.

Do not stand close to the trunk; keep as much as four feet away.

Do not stand where the branches are close overhead.

It is better to sit or squat than to stand. Some statistics have been gathered regarding deaths by lightning outdoors, which show that considerably more people are killed in the open than under trees; but these figures do not prove anything, because it is not known what proportion of people caught in storms take shelter under trees.

Lightning and Trees.—There is considerable difference in the liability of different trees to lightning stroke. In Belgium a record was kept for several years showing the number of trees of different kinds that were struck. Poplar suffered most, oaks next and elms third. Pine, fir and chestnut trees are also struck frequently, while the beech, birch and maple are not damaged much. The beech seems to be the safest of all, and for this reason is a good tree to plant in places where people or cattle are likely to take refuge under it in a storm. Observations of lightning strokes were carried on for a period of eight years in a German forest of 45,000 acres. Although nearly 70% of the forest consisted of beeches, there were only 21 cases of damage found. Oaks, which make up 11% of all the trees, were struck 20 times, and firs, which constituted about 6% of the forest, were struck 59 times. It does not follow that a beech tree close to a house will keep off lightning. The beech is safe only because it does not attract the lightning. The location of a tree, however, has more to do with its liability to lightning stroke than its shape or kind.

Resuscitation.—Persons sometimes receive violent electric shocks and appear to be killed, but revive after a time if their breathing is kept up artificially. If someone is struck or shocked and stops

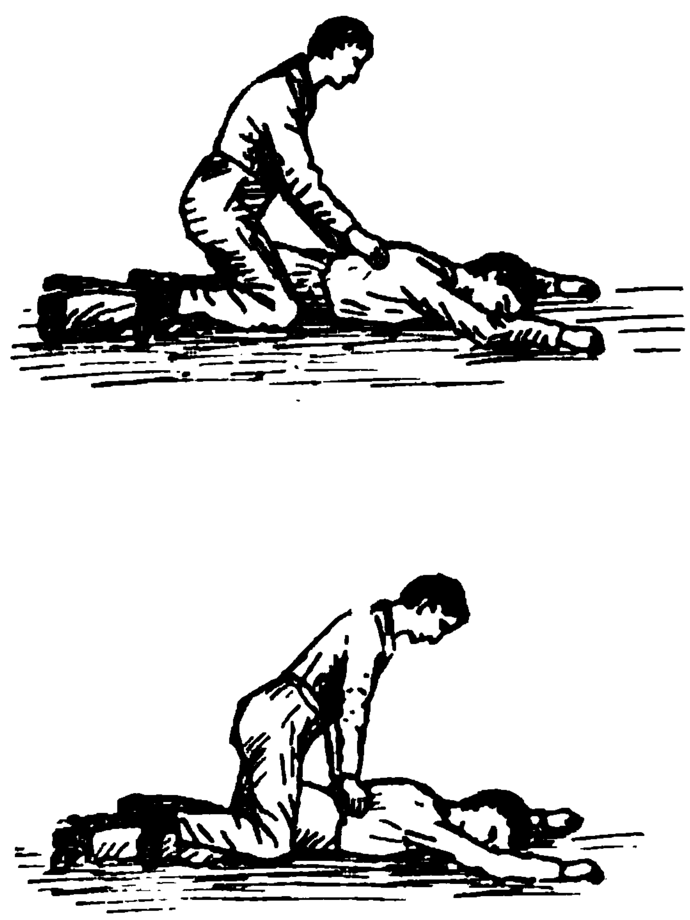


Fig. 18. Producing artificial breathing.

breathing, begin at once to force the breathing, first seeing that there is nothing tight around the neck and no obstruction in the throat. Reach in the mouth and pull the tongue forward and see that it stays so. Loosen all clothing that is tight, but do not uncover the patient unnecessarily. Place the patient flat on the floor, face down, but with the head turned to one side, and with the arms stretched out above the head, kneel with one knee each side of his thighs, place your hands on his lower ribs and press firmly down and inward, gradually throwing your own weight against him, hold the pressure for an instant and then slowly let go. Do this about once in five seconds. This should be continued for at least two hours, if necessary, or until a doctor arrives and finds that the heart has stopped beating. Cases are known of patients recovering after three hours of forced breathing. The work should not be done in a hurried or excited manner. Keep the patient warm. Let someone rub his limbs, stroking them upward, toward the heart, so as to assist the circulation. If the work takes more than a very few minutes, have your assistant apply cloths dipped in hot water and wrung out, to the chest and sides and any other part of the body that may be getting cold, but do not let anything interfere with your efforts to make the patient breathe. Stiffness or resistance to your movements is a good sign. Keep watch for any sign of natural breathing and as soon as it appears, make your movements fall in with it and help it out.

Grounding Wire Fences.—Many cattle are killed every year by standing close to wire fences during storms. Lightning strikes the wire and has no means of getting into the ground, but spreads along the wires and jumps to near by objects.

This danger can be avoided by making a ground connection with the fence every hundred feet. If the fence is long or if there are only a few cattle in the enclosure the ground connections might be put two hundred feet apart, although the protection is not quite so good with this spacing.

Drive a crow-bar four or five feet into the ground and pull it out, run a wire down the hole, making sure that it reaches bottom,

give it about two turns around each strand of the fence and a few extra turns around the top wire. If the fence is of wire mesh or network, it is only necessary to make a connection at the bottom. No. 10 B. & S. copper wire is recommended for this work, but if the fence is already old and will have to be replaced in three or four years, No. 8 or No. 10 galvanized iron wire might as well be used. Using the iron wire would save three or four cents on each connection. If the fence is just being put up, fasten the ground wire to the post before it is set in the hole. If the hole is less than four feet deep the wire should be run below the bottom of the post.

Protecting Hay Stacks.—There is much loss from hay stacks set fire to by lightning A method is suggested here for protecting hay stacks. The apparatus can be put together at odd moments and at small expense. It can be set up over the stack in a few minutes, taken down when the stack is removed, and kept for use the next year.

Get four light sticks about 1 inch by 2 inches by 6 feet, and one piece, say, 2 inches by 2 inches by 10 feet. Sharpen the ends so that they can be thrust into the stack, and drive spikes through to keep them from working further in than is intended. Get a five foot iron rod and fasten it to the end of the large stick so that it projects three feet File the rod to a point. Fasten to it four No. 8 galvanized iron wires long enough to reach from the top of the stack to the ground. Get four 5/8-inch pointed iron bars, four feet long, and fasten these to the ends of the wires The four lighter sticks are to

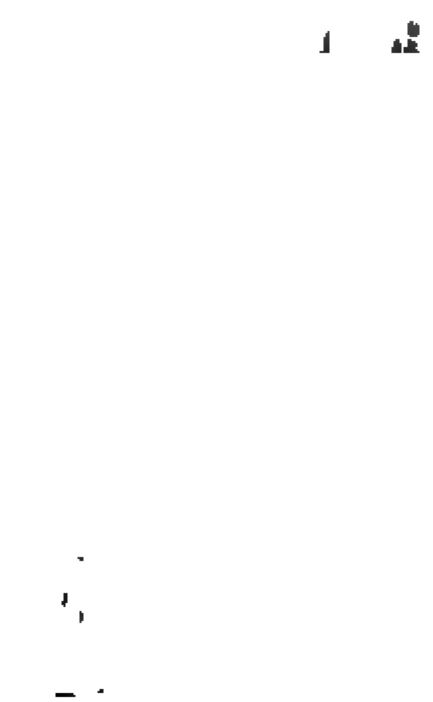


Fig. 10. Apparatus for protecting a haystack.

serve as props to keep the wires well away from the hay. Drive a large spike into the end of each, cut off the head and file it to a point. Drive in a nail next to the large spike so that the wire will wedge between them and make a good contact with the spike. The stick with the wires attached is put in the top of the stack, and the wires stretched out in four directions. Drive the iron rods into the ground. Dig a pit next to each rod and pour in a bucket of salt water. If the stack remains in the field for several weeks of dry weather pour in some more water.

Another method of protecting stacks is to set a light pole in the ground tall enough to reach eight or ten feet above the stack. Attach a rod of No. 4 copper wire to the pole pointed at the top and making a good ground connection at the bottom. Stack the hay around the pole. This will not give as good protection as the first method.

Hay Barns and Silos.—The question has been raised whether ventilators in hay barns increase the risk. Open windows or ventilators may cause greater risk if the barn is not rodded. If a rod with a point is placed directly over the ventilator, the barn is probably safer than it would be without any opening for change of air.

Wooden silos are easily protected with a rod and need the protection. If the silo is made of reinforced concrete it is doubtful whether a rod would be of much use. A lightning stroke would probably scale off and crack the concrete here and there, but not do very serious damage.

THE UNIVERSITY OF MISSOURI BULLETIN

Bulletin No. 8

ENGINEERING EXPERIMENT STATION SERIES

VOLUME 3. NUMBER 2

FIRING TESTS ON MISSOURI COAL

BY

H. N. SHARP

UNIVERSITY OF MISSOURI

COLUMBIA, MISSOURI

June, 1912

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1st, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and one research assistant together with a number of teachers who have undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

NOTE BY THE EDITOR.

One can hardly overemphasize the importance of an adequate supply of local coal for domestic and industrial use or the value of definite information in regard to its location and quality.

The Engineering Experiment Station of the University of Missouri has published a bulletin, Vol. II, No. 1, "The Heating Value and Proximate Analysis of Missouri Coals", a reprint of a bulletin by Professor C. W. Marx and Dr. Paul Schweitzer, first issued in 1901. There is also available a bulletin "The Storage of Coal" by E. A. Fessenden and J. R. Wharton issued prior to the establishment of the Station. Both of the above are somewhat technical in character, whereas the present bulletin is more directly practical, and shows that the Missouri coal used compares favorably with other bituminous coals mined in the middle west, a fact confirmed by some boiler acceptance tests made under the direction of the writer.

Of prime importance in considering the mining, sale, and use of Missouri coal is the effect of the thickness of vein upon the cost of mining. As more than half the total cost of coal purchased outside the state is for freight and haulage to cities in the middle of the state, there is great opportunity for the development of local coal fields with short-haul transportation. Successful competition with outside coal depends on the reliability of supply, which probably necessitates storage, and on the total cost delivered. If the cost of mining and transportation of Missouri coal for local use can be made even slightly less than competing coal of corresponding heating value, and if coal is available as needed, sufficient capital for development should be easily obtainable, with resulting economy to both mine operators and users.

The cost of transporting short distances can easily be made low by providing proper facilities, but on the other hand the cost of mining very thin veins may be prohibitively high, and unfortunately the coal veins thin out considerably near the edges where they outcrop.

To get the approximate effect of the thickness of vein upon the cost of mining I tabulated the data contained in the "Twenty-first Annual Report of the Bureau of Mines and Mine Inspection, State of Missouri, 1907", and for convenience constructed the accompaning chart which shows the maximum, average, and minimum costs per ton of mining coal plotted against the thickness of the vein.

Naturally other influences affect the cost of mining, so the chart should be considered as a general representation, not as an exact measure of the cost in a particular instance. For example, the chart evidences that it will not generally pay to mine very thin veins except possibly for individual use where the cost of transportation is very low.

H. B. SHAW.

INTRODUCTION.

Half of the 114 counties in Missouri, more than one third of the total area of the state, are underlaid with coal. The coal is bituminous (soft) and compares favorably with other Western bituminous coals in heating value and general adaptability for power plant purposes. The coal mining industry, however, is not very well developed and a great deal of the coal used in the state for domestic and industrial purposes is shipped in from the neighboring states of Illinois, Kansas and Oklahoma.

The price of Missouri coals at the mines is somewhat higher than in the neighboring states, Illinois for example.* This is because the methods of mining are generally not as good, the coal seams are not as thick and high freight rates make it unnecessary to maintain low prices in competition with a distant market. An increased use of native Missouri coal in preference to that shipped in from neighboring states would stimulate the mines of the state to greater activity and more modern methods of mining. The price of coal at the mine could then be lowered and both consumer and producer would be benefited.

Many coal consumers use Missouri coal. In many cases the results are entirely satisfactory, in others difficulties have arisen to cause dissatisfaction and in some cases have led to the use of coal from other states. It is quite possible that much of the dissatisfaction has been caused by improper methods of handling the coal.

It is the purpose of this bulletin to interest the coal users of the state in Missouri coal and to point out methods and controlling conditions by which better economy may be obtained and the coal burned satisfactorily in small hand fired power plants. No set of definite rules can be given because of the widely different conditions which obtain at different plants, but the discussion covers the nature of the coal, its handling and combustion, together with other factors affecting the operation of a boiler plant. These are all of importance to every one who is interested in fuel burning and fuel economy.

Most of the smaller power plants of the state are equipped with hand fired, return tubular boilers. The boilers and setting are not generally kept in the best condition. More or less scale is allowed to accumulate in the boiler and the setting leaks are usually large.

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*Illinois bituminous coal is used as a basis of comparison in several places in this bulletin because Illinois is the largest coal producing state in the Middle West and because the quality of Illinois coal is generally well known.

The discussion in this bulletin is based on a number of tests made with a representative Missouri coal, hand fired under a return tubular boiler. The boiler and setting were not in good condition. They probably represent about average practice and the results obtained are such as might be expected from the ordinary small plant.

Particular attention is called to the use of slack and screenings. These are very low priced, compared with run of mine and lump coal. They can be used with economy if carefully fired.

Missouri coal is often condemned because of clinker troubles. These may also be largely overcome by careful firing.

PART I

FIRING TESTS ON MISSOURI COAL

TESTS.

The tests were made on one of the boilers in the power plant of the University of Missouri. The boiler is a return tubular boiler, hand fired. The principal dimensions of the boiler are given on page 9.

The fireman used in the tests was selected from the regular force of firemen at the power plant. The same fireman fired all the tests. He handled the fire about as he did every day under ordinary working conditions except that he fired a certain number of shovelsful of coal at regular intervals and was told when to slice or clean. The fire was raked and leveled occasionally and kept free from holes.

The operating conditions were kept as nearly uniform as possible for all the tests. Only one condition was allowed to vary for any one test and this the one whose effect was being investigated.

The boiler was kept in regular use throughout the entire period over which the tests extended. It was cleaned and overhauled at regular intervals just as though no tests were in progress. All this was done in order that the test results might be representative of ordinary power plant operation. Washing out the boiler, cleaning tubes, etc., varied the operating conditions somewhat, so that the tests are arranged in several groups, separated by cleaning periods. The condition of the boiler for any one group of tests was not changed in any way except that it became dirty as the time for its regular cleaning approached.

The test apparatus was left set up ready for use. When a test was to be run the steam pressure and water level were brought to their normal mark; then the fire was cleaned, fired with Missouri coal and the test started with the first firing after cleaning. The same plan was folowed when the test was finished, the test being stopped at the first firing after cleaning. With the exception of the variation in firing methods which were being investigated, the tests were all run under ordinary operating conditions.

An injector was used to feed the boiler. Its capacity was too large so that it had to be started and stopped throughout the test. The feed water was weighed by a Kennicott automatic water weigher; the weigher was tested and found accurate within one-half of one per cent.

The flue gas temperature was recorded on a Bristol recording

electric pyrometer which was compared with a high grade mercury thermometer and found accurate within a few degrees.

A record of the percent of a carbon dioxide in the flue gases was made with a Uehling continuous CO_2 recorder. This was checked occasionally by an Orsat gas analysis apparatus and found accurate.

The coal was weighed on the platform scales regularly used in the boiler room.

The steam pressure was taken from a new Ashcroft guage, carefully calibrated. The steam quality was determined with a throttling calorimeter.

All the coal used, except that for test No. 6, was stored in a room in the power house protected from the effects of the weather. The coal used in test No. 6 was exposed to a heavy snow. The coal varied from lump coal to slack. The lump coal was broken up before firing.

Tests Nos. 1, 2, 3, 4 and 5 were made with Illinois coal of average quality. All the other tests were made with a typical Missouri coal from Higbee, Mo.

Special care was taken in sampling the coal used in the tests for the determination of the proximate analysis and calorific value. A shovelful of coal was taken from each car (small boiler room coal passing cars) of coal used during a test when the car was about half full. These were kept until the test was finished, then broken and quartered down to about two pounds. In spite of all precautions taken in sampling it is believed that the ash, as shown by the proximate analysis, is too high is tests Nos. 14, 18 and 27, so that the efficiencies of these tests are probably higher than they should be. The high ash shown by the analysis may be caused by including an exceptionally slaty piece of coal in the sample. For this reason these three tests are disregarded in most of the conclusions drawn. The coal sample was analysed as soon as possible after the test. The heating value was determined by a calorimeter of the Parr type.

TEST DATA.

(The figures in parenthesis refer to the code for boiler tests of the American Society of Mechanical Engineers.)

Tests made by H. N. Sharp, for the University of Missouri Engineering Experiment Station, at the University Power Plant, Columbia, Missouri.

Kind of boiler, Horizontal return tubular.

Kind of fuel, Tests Nos. 1, 2, 3, 4, 5.

Illinois run of mine coal.

All other tests—Higbee, Mo., run of mine coal.

Kind of furnace, hand fired, plain grate.

Method of starting and stopping the test, alternate.
Number of boiler (plant number) 7.

(3) Grate surface	28 sq. ft.
(3.1) Width of grate	6.5 ft.
(3.2) Length of grate	4.31 ft.
(4) Height of furnace (distance from top of grate to shell)	21.5 inches
(5) Approximate width of air space in grate	9-16 inches
(6) Proportion of air space to whole grate area	34.5%
(7) Water heating surface	1200 sq. ft.
(7.1) Outside diameter of shell	5.5 ft.
(7.2) Length of shell	16 ft.
(7.3) Number of tubes	72
(7.4) Diameter of tubes — Outside	3.75 inches
(7.4) Diameter of tubes — Inside	3.51 inches
(7.5) Length of tubes exposed	16 ft.
(9) Ratio $\frac{\text{Water heating surface}}{\text{Grate surface}}$	42.8

Test Number	Date 1912	Weather	Object of Test	Date of B—Blowing Down C—Cleaning S—Scraping	Duration of Test Hours	Steam Pressure, pounds per sq. inch Gauge	Steam Pressure, pounds per sq. inch Absolute	Barometer inches of mercury	Draft between Damper and Boiler, inches of water
	(1)				(2)	(11)		(11.1)	(12)
1	Feb. 8	Cloudy-Snow	Preliminary	C. Jan. 21	8.40	103.	117.4	29.3	0.6
2	21	Cloudy-Snow	Preliminary	C. Feb. 18	10.07	98.	112.3	29.16	0.62
4	28	Cloudy	Preliminary	....	9.93	99.5	113.9	29.38	0.64
5	Mar. 1	Clear	Preliminary	....	9.89	106.	120.6	29.74	0.61
6	Mar. 7	Cloudy-Snow	Firing Interval	C. Mar. 3	9.98	100.	114.3	29.18	0.62
7	9	Clear	Firing Interval	....	9.82	104.	118.5	29.55	0.64
8	11	Cloudy-Rain	Firing Interval	....	8.50	99.	133.3	29.04	0.63
9	12	Cloudy-Rain	Fire Thickness	....	9.53	103.2	117.5	29.09	0.62
10	13	Clear	Firing Method	....	9.58	102.6	116.9	29.13	0.61
11	Mar. 29	Clear	Preliminary	C. Mar. 24	8.68	102.	116.2	28.94	0.47
12	Apr. 2	Clear	Firing Interval	S. Mar. 26	10.13	98.7	112.9	29.0	0.41
13	3	Clear	Firing Interval	....	10.47	97.6	112.	29.24	0.41
14	4	Clear	Firing Interval	....	10.20	97.	111.4	29.32	0.4
15	5	Clear	Draft	....	10.28	100.5	114.8	29.1	0.28
16	6	Cloudy	Draft	....	9.88	97.3	111.7	29.39	0.25
17	8	Clear	Draft	....	10.17	95.3	109.7	29.4	0.4
18	Apr. 16	Cloudy	Cleaning Boiler	B.&S.Apr. 12	10.54	96.2	110.5	29.2	0.42
19	24	Clear	Firing Method	C. Apr. 14	9.67	96.5	111.	29.43	0.42
20	25	Cloudy-Rain	Firing Method	....	10.15	98.7	113.	29.15	0.42
21	26	Clear	Fireman B	....	10.17	99.5	113.8	29.06	0.41
22	May 8	Clear	Firing Method	C. Apr. 28	10.13	97.5	111.7	28.98	0.4
23	9	Clear	Setting Leakage	S. May 2	10.17	98.	112.3	29.02	0.41
24	10	Showers	Setting Leakage	....	9.90	95.	109.1	28.77	0.47
25	May 14	Clear	Scraped Tubes	C. May 12	9.98	105.1	119.5	29.26	0.4
27	17	Clear	Firing Method	S.&B.May 13	10.03	100.	114.4	29.33	0.41
28	21	Clear	Moisture	....	9.88	99.8	114.1	29.05	0.41
30	May 24	Cloudy	Forcing	C. May 23	9.35	99.1	113.4	29.21	0.52

Test Number	Temperature of External Air, Degrees F.	Temperature of Fire Room, Degrees F.	Temperature of Steam, Degrees F.	Temperature of Feed Water, Degrees F.	Temperature of Flue Gases, Degrees F.	Fuel, Kind, Size and Condition	Weight of Coal as Fired, pounds	Weight of Dry Coal, pounds	Weight of Ash and Refuse, pounds	Combustible consumed, pounds	Percent of Ash and Refuse in Dry Coal	Fixed Carbon, Percent	Volatile Matter, Percent	Moisture, Percent.	Ash, Percent.
	(15)	(16)	(17)	(18)	(21)	(23)	(25)	(27)	(28)	(30)	(31)	(32)	(33)	(34)	(35)
1	19	47.2	339.6	60.5	777	Illinois, R. of M., damp, dirty	7147	6250	1026	5325	16.42	41.5	35.25	12.5	10.58
2	27	60.8	336.3	60.8	748	Do.	7698	6760	927	5845	13.7	42.6	37.7	12.2	7.5
4	28	57.	337.3	60.3	614	Do.	6080	5355	826	4527	15.41	42.55	36.2	12.0	9.25
5	22	53.1	332.0	59.8	653	Do.	6115	5280	994	4280	18.81	40.3	36.65	13.5	9.55
6	34	62.4	337.6	60.3	751	Mo., R. of M., ⅓ slack, wet	8077	7453	1307	6147	17.52	45.6	35.4	7.73	11.27
7	20	51.8	340.3	59.9	786	Mo. R. of M, little slack, dry	8451	7679	1341	6338	17.48	47.75	35.92	9.2	8.12
8	30	61.7	336.9	59.9	735	Mo., R. of M., ⅓ slack, wet	6991	6331	.....	.....	......	46.15	35.9	9.44	8.51
9	30	64.7	339.7	60.0	815	Do.	9487	8478	1929	6551	22.73	42.78	32.6	10.64	13.98
10	26	59.	339.3	59.9	719	Do.	8513	7481	1405	6076	18.78	41.2	32.58	12.12	14.1
11	48	75.	338.8	61.3	660	Mo., R. of M., lump, dry ...	5412	4998	.....	.....	......	43.35	34.27	7.65	14.73
12	48	72.5	336.7	61.3	713	Do.	7660	7019	1089	5931	15.5	45.6	37.05	8.98	8.37
13	51	75.	336.0	61.6	731	Do.	7812	7184	1231	5954	17.12	44.05	33.0	8.04	14.91
14	64	84.7	335.6	61.3	672	Mo., R. of M., ¼ slack, dry	7368	6816	1126	5690	16.52	38.1	27.43	7.47	27.0
15	68	89.8	337.9	61.6	672	Do.	6872	6267	1111	5156	17.72	45.72	32.82	8.8	12.66
16	59	88.8	335.9	61.8	673	Do.	6097	5569	1035	4534	18.58	45.15	32.89	8.66	13.3
17	51	77.	334.6	61.7	662	Mo., R. of M., ⅓ slack, dry	6732	6078	958	5111	15.74	45.3	32.5	9.72	12.48
18	46	70.8	335.0	61.6	665	Do.	7403	6829	1178	5652	17.24	42.7	32.5	7.75	17.05
19	60	85.7	335.4	61.8	681	Do.	5647	5238	801	4537	15.39	45.8	37.05	7.25	9.9
20	60	82.6	336.7	62.0	713	Do.	6235	5684	885	4790	15.55	44.63	35.4	8.84	11.18
21	63	87.1	337.2	61.9	729	Do.	6134	5589	974	4616	17.41	44.83	35.34	8.89	10.94
22	68	92.6	335.9	62.3	749	Do.	6797	6218	1091	5128	17.53	43.1	34.17	8.52	14.21
23	68	94.5	336.2	62.6	690	Mo., R. of M., ¼ slack, dry	6689	6237	1182	5105	18.15	44.0	37.05	6.76	12.19
24	72	94.4	334.2	62.4	645	Mo., R. of M., ½ slack, dry	5983	5401	1220	4208	22.58	43.85	35.0	9.72	11.43
25	55	80.1	340.9	61.5	682	Do.	6740	6268	1017	5242	16.21	44.9	35.57	7.01	12.52
27	55	82.	337.6	61.7	780	Do.	7232	6491	1147	5344	17.67	38.81	31.88	10.24	19.67
28	76	96.7	337.4	62.8	745	Do., with 5.62% water add.	6547	5632	968	4471	17.10	39.9	33.2	13.98	12.92
30	74	92.7	337.0	62.8	764	Mo., R. of M., ⅓ slack, dry	7691	7123	1214	5909	17.05	47.72	35.2	7.39	13.68

Test Number	Dry Coal Consumed per Hour, pounds.	Combustible Consumed, per hour, pounds.	Dry Coal per sq. ft. of Grate per Hour, pounds.	Combustible per sq. ft. of Heating Surface, per Hour, pounds.	B. t. u. per pound of Dry Coal, by Calorimeter.	B. t. u. per Pound of Combustible.	Quality: Moisture in Steam, Percent.	Quality: Factor of Correction (dry steam unity)	Total Water fed to Boiler, pounds.	Equivalent Water, from and at 212 degrees F., pounds.	Water Actually Evaporated, Corrected for Steam Quality, lbs.	Factor of Evaporation	Equivalent Water into Dry Steam, pounds.
	(46)	(47)	(48)	(49)	(50)	(51)	(54)	(56)	(57)	(58)	(59)	(60)	(61)
1	745.	622.6	27.6	0.556	12221	13896	0.535	99.594	34751	41559	34610	1.1959	41340
2	672.5	581.	24.9	0.518	12822	14134	0.75	99.43	38514	46038	45775	1.1953	45775
4	573.	485.	21.2	0.443	12790	14296	0.137	99.9	29062	34749	29033	1.1957	34715
5	534.5	483.	19.78	0.387	12645	14216	0.365	99.719	27910	33411	27831	1.1971	33317
6	746.	615.5	26.65	0.513	12708	14474	0.239	99.819	36901	44119	36834	1.1956	44039
7	781.5	644.5	27.9	0.537	13440	14770	0.069	99.948	42339	50467	42317	1.1967	50441
8	745.	....	26.6	....	13210	14590	0.137	99.896	34139	40786	34092	1.1947	40730
9	889.	687.	31.75	0.572	12068	14320	Dry	Dry	43674	52252	43674	1.1964	52252
10	782.	635.	27.92	0.529	12180	14550	Dry	Dry	41623	49798	41623	1.1964	49798
11	575.	....	20.55	....	12022	14320	0.205	99.85	28741	34317	28695	1.1949	34263
12	692.	585.	24.7	0.487	13120	14450	0.056	99.969	38507	45995	38495	1.1945	45976
13	690.	572.	24.65	0.476	11910	14220	0.079	99.94	39520	47187	39496	1.1940	47159
14	667.5	558.	23.85	0.465	9690	13790	0.181	99.861	36350	43411	36299	1.1943	43350
15	610.	501.5	21.8	0.418	12410	14420	0.125	99.905	32870	39265	32839	1.1946	39227
16	564.	459.	20.15	0.383	12077	14137	0.442	99.664	30338	36212	30236	1.1939	36090
17	594.	502.5	21.35	0.418	12697	14119	0.453	99.655	35034	41818	34918	1.1936	41674
18	647.7	535.5	23.13	0.437	11786	14292	0.011	99.992	40333	48147	40330	1.1937	48148
19	542.	459.	19.33	0.383	13333	14926	Assumed	99.8	30586	36507	30525	1.1936	36484
20	560.	472.	20.0	0.294	12846	14634	Assumed	99.8	33389	39856	33322	1.1937	39776
21	549.5	453.5	21.22	0.378	12809	14556	Assumed	99.8	32234	38487	32170	1.1940	38410
22	613.5	506.	21.9	0.422	11807	13978	0.419	99.681	34299	40926	34189	1.1932	40795
23	613.	502.	21.9	0.418	12792	14496	0.25	99.807	32163	38367	32102	1.1929	38293
24	546.	425.	19.5	0.354	12972	14859	0.147	99.888	26124	31155	26044	1.1926	31120
25	628.	525.	22.4	0.437	12637	14607	0.114	99.913	37721	45084	37688	1.1952	45045
27	646.	532.	23.05	0.443	11121	14118	0.942	99.284	36670	43788	36407	1.1941	43174
28	573.	455.	20.50	0.379	12637	14873	0.432	99.671	31898	38048	31788	1.1930	37923
30	762.	631.5	27.2	0.526	12406	14355	0.023	99.982	37682	44951	37675	1.1929	44942

Test Number.	Water Evaporated per Hour, corrected for Quality, pounds.	Equivalent Evaporation per Hour, from and at 212 degrees F, pounds.	Equivalent Evaporation per Hour, per sq. ft. of Heating Surface, pounds.	Boiler Horse Power Developed (34.5 pounds from and at 212 degrees per hour).	Per cent of Rating Developed.	Water Apparently Evaporated per pound of Coal as Fired, pounds.	Equivalent Evaporation per Pound of Coal as Fired, pounds.	Equivalent Evaporation per Pound of Dry Coal, pounds.	Equivalent Evaporation per Pound of Combustible, pounds.	Efficiency of Boiler, per cent.	Efficiency of Boiler and Grate, per cent.	Cost of Evaporating 1000 Pounds of Water, Observed Conditions*	Cost of Evaporating 1000 Pounds of Water from and at 212 degrees F.*
	(62)	(63)	(64)	(65)	(67)	(68)	(69)	(70)	(71)	(72)	(73)	(75)	(76)
1	4125	4842	4.03	140.3	93.6	4.87	5.74	6.62	7.92	55.3	52.55	$.1027	$.0863
2	3690	4550	3.79	131.9	87.8	5.00	5.95	6.78	7.83	53.75	51.3	.10	.0841
4	2925	3484	2.91	101.3	67.6	4.88	5.71	6.48	7.66	52.0	49.2	.1023	.0877
5	3377	3367	2.81	97.5	65.0	4.56	5.45	6.31	7.78	53.1	48.3	.1096	.0912
6	3689	4411	3.67	127.8	85.2	4.57	5.45	5.91	7.17	48.05	45.15	.1094	.0918
7	4307	5134	4.27	148.9	99.2	5.02	5.97	6.57	7.965	52.3	47.4	.0997	.0838
8	4011	4792	3.99	139.0	92.7	4.88	5.83	6.43	....	....	47.25	.1024	.0859
9	5482	5482	4.57	158.9	105.9	4.60	5.51	6.165	7.98	54.0	49.5	.1087	.0908
10	4355	5205	4.34	150.9	100.4	4.89	5.79	6.66	8.19	54.6	53.1	.1021	.0863
11	3242	3947	3.29	114.4	76.3	5.32	6.33	6.86	....	....	55.3	.094	.0789
12	3798	4535	3.78	131.3	87.7	5.08	6.00	6.55	7.75	52.0	48.4	.0995	.0833
13	3780	4520	3.76	131.0	87.3	5.06	6.03	6.56	7.92	54.0	53.45	.0988	.0829
14	3557	4250	3.54	123.1	82.0	4.98	5.88	6.365	7.62	53.6	63.75	.1013	.0851
15	3200	3820	3.182	110.8	73.8	4.78	5.71	6.37	7.62	51.3	49.	.1045	.0876
16	3056	3652	3.04	106.8	71.2	4.98	5.92	6.48	7.96	54.3	52.1	.1003	.0845
17	3440	4110	3.42	119.0	79.3	5.21	6.19	6.85	8.16	53.75	52.3	.0962	.0808
18	3825	4560	3.797	132.1	88.1	5.45	6.50	7.05	8.52	57.8	58.1	.0918	.0769
19	3160	3770	3.195	112.7	75.1	5.42	6.46	6.96	8.22	53.4	50.65	.0928	.0774
20	3290	3920	3.26	113.6	75.8	5.35	6.34	7.00	8.30	55.0	52.8	.0934	.0788
21	3165	3780	3.15	109.4	73.0	5.27	6.26	6.875	8.325	55.5	52.1	.0944	.0799
22	3370	4030	3.365	117.0	78.0	5.05	6.01	6.56	7.95	55.2	53.83	.099	.0833
23	3160	3770	3.14	111.0	74.0	4.81	5.73	6.145	7.50	50.2	46.6	.104	.0873
24	2640	3145	2.62	90.2	60.1	4.365	5.20	5.76	7.40	48.3	43.1	.1147	.0962
25	3780	4510	3.76	130.7	87.2	5.60	6.68	7.185	8.60	57.1	55.1	.0893	.0748
27	3625	4330	3.61	125.5	83.7	5.025	6.01	6.70	8.13	56.8	58.3	.0995	.0833
28	3215	3835	3.195	111.1	74.1	4.87	5.79	6.74	8.48	55.3	53.2	.1026	.0864
30	4030	4805	4.05	139.2	92.9	4.90	5.85	6.31	7.61	50.7	48.3	.102	.0855

*If coal costs $1.00 per ton.

Test Number.	Method of Firing	Thickness of Fire, Inches.	Firing Intervals, Minutes.	No. of Slicings.	No. of Cleanings, taking out Clinker.	Per cent CO_2 in Flue Gases.	REMARKS.
	(80)	(81)	(82)	(83)		(84)	
1	Spreading	8.	7.03	1	1	9.5	Firing Interval Irregular.
2	Do	8.	8.39	1	1	9.3	Do
4	Do	7.2	10.45	2	0	7.7	Do
5	Do	6.07	8.86	4	0	6.4	Do
6	Do	5.72	7.59	8	0	8.4	Efficiency appears low because coal sample dried before analysed.
7	Do	5.12	4.91	7	0	8.1	
8	Do	5.42	9.81	6	....	8.2	Ash not weighed in this test.
9	Do	9.87	6.02	2	2	10.8	Thick fire, large capacity.
10	Alternate	5.91	5.0	4	1	9.0	Large capacity.
11	Spreading	5.6	9.48	1	1	7.22	Ash not weighed in this test. CO_2 appears too low, exh't'd chemical
12	Do	5.0	5.2	6	0	8.8	
13	Do	5.44	7.45	4	0	9.8	
14	Do	5.21	9.72	3	0	10.0	Ash abnormally high, making efficiency appear too high.
15	Do	5.35	7.52	3	0	11.5	
16	Do	5.61	7.52	2	1	12.1	
17	Do	5.93	7.72	2	0	10.2	
18	Do	5.98	7.63	3	0	10.0	Ash abnormally high, making efficiency appear too high.
19	Alternate	6.1	7.44	2	0	9.8	Steam quality assumed, accident to calorimeter.
20	Do	6.0	7.52	2	0	10.0	Do
21	Do	4.7	7.44	2	0	9.5	Do
22	Do	5.47	5.47	2	1	10.1	
23	Do	5.17	5.55	4	2	8.1	16″ x 16″ door in rear of setting open about 4″.
24	Do	5.21	5.17	4	2	6.9	16″ x 16″ door in rear of setting wide open.
25	Do	5.12	5.8	5	0	10.2	
27	Spreading	5.03	5.52	4	0	10.5	Ash abnormally high, making efficiency appear too high.
28	Alternate	4.73	7.71	2	0	9.9	5.62% water added to coal to find the effect of wetting.
30	Spreading	5.24	5.61	3	2	11.8	Thickness of fire varied from 4½ to 8 inches.

THE TEST RESULTS.

General.

It is noticeable that the Missouri coal gave as good, or slightly better, average efficiency than the Illinois coal. The boiler was in a little better condition for the Missouri coal tests than for the Illinois coal. This may account for the slightly higher efficiency with the Missouri coal. These two kinds of coal are so much alike that there should be but little difference in the economic results obtained from them. The fireman had no difficulty in firing the Missouri coal and stated that he would as soon fire one as the other.

These observations are confirmed by the United States Geological Survey tests with Illinois and Missouri coals fired under a Heine boiler. These tests comprised a large number of trials with Illinois coals and a smaller number with Missouri coals. The average boiler and grate efficiency with the Illinois coals was about 64%, while that for Missouri coals was 62%.

Firing Methods.

The system of firing employed, whether "spreading" or "alternate", appears to have but little effect upon the efficiency. The efficiency of boiler and grate for all of our tests on Missouri coal grouped by the method of firing is given in Table I.

TABLE I.

EFFECT OF METHOD OF FIRING.

SPREADING METHOD			ALTERNATE METHOD		
Test No.	Efficiency of Boiler.	Efficiency of Boiler and Grate.	Test No.	Efficiency of Boiler.	Efficiency of Boiler and Grate.
	%	%		%	%
6	48.05	45.15?	10	54.6	53.1
7	52.3	47.4	19	53.4	50.65
8	.....	47.25	20	55.	52.8
9	54.	49.5	21	55.5	52.1
11	.....	55.3	22	55.2	53.83
12	52.	48.4	23	50.2	46.6
13	54.	53.45	24	48.3	43.1
14	53.6	63.75?	25	57.1	55.1
15	51.3	49.	28	55.3	53.2
16	54.3	52.1			
17	53.75	52.3			
18	57.8	58.1?			
27	56.8	58.3?			
30	50.7	48.3			
Mean	53.21	52.02	Mean	53.84	51.16
Mean, with tests marked (?) omitted,		50.3			

If the results of all the tests are taken the spreading method appears to be slightly better, but if certain tests (marked ?) are thrown out because of probable errors in sampling the coal for the determination of the calorific value, the alternate method gives results a very little better than the spreading method. The difference is so small that it might easily be explained by many other causes, such as the thickness of the fire, the draft or the firing interval.

Further light may be shed on the question of the method of firing by examining certain tests with all the operating conditions nearly the same. The tests collected in Table II were run with a fire thickness between 4.7 inches and 6.1 inches, the average being 5.49 inches. The draft ranged between .4 inches and .47 inches of water,

averaging .42 inches. The load carried was from 110 to 131 boiler horsepower and the firing interval varied as indicated.

TABLE II.

EFFECT OF METHOD OF FIRING.

SPREADING					ALTERNATE				
Test No.	Draft, inches.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.	Test No.	Draft, inches.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.
				%					%
12	.41	5.	5.2	48.4	22	.4	5.47	5.47	53.83
13	.41	5.44	7.45	53.45	25	.4	5.12	5.3	55.1
17	.4	5.93	7.72	52.3	19	.42	6.1	7.44	50.65
11	.47	5.6	9.48	55.3	20	.42	6.	7.52	52.8
					21	.41	4.7	7.44	52.1
			Mean	52.36					
									52.89

This table of test results, selected with the idea of eliminating all the variables except the two methods of firing, shows that there is but little choice between them, the alternate method giving slightly better results.

This conclusion is confirmed by the following results published by the United States Bureau of Mines, Bul. No. 23. This bulletin gives the data of a very large number of boiler tests upon a 210 H. P. Heine boiler, handfired, with coal from all parts of the United States. Table III is compiled for the several Missouri coals used.

TABLE III.

RESULTS WITH MISSOURI COALS.

U. S. Geological Survey Fuel Testing Plant. 210 H. P. hand-fired Heine boiler.

Test No.	Designation of Coal.	Kind of Coal.	Draft, inches.	Thickness of Fire, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate. %
ALTERNATE METHOD.						
326	Mo. 6	Lump	.73	6	3.6	63.40
327	Mo. 6	Lump	.75	6	3.9	60.64
15	Mo. 1	Small coal and slack	.37	8	4.5	62.32
70	Mo. 4	Small coal and slack	.52	8	5.6	60.06
319	Mo. 5	Run of mine	.61	8	4.2	61.57
329	Mo 7A	No. 1 nut	.60	8	3.5	61.26
330	Mo. 7A	No. 1 nut	.71	8	3.3	60.49
12	Mo. 1	Run of mine	.40	9	4.7	63.18
320	Mo. 5	Run of mine	.73	10	3.6	62.90
332	Mo. 10	No. 2 nut	.71	10	4.1	55.92
					Average	61.17
SPREADING METHOD.						
78	Mo. 3	Small coal and slack	.70	6	6.9	58.94
37	Mo. 2	Small coal and slack	.62	7	6.7	59.45
44	Mo. 2	Small coal and slack	.32	7	8.3	60.68
77	Mo. 3	Small coal and slack	.65	7	7.1	56.93
					Average	59.00

If tests Nos. 332 and 77 are omitted as being considerably lower

than the others the efficiency becomes 61.76% for the tests with alternating firing and 59.69% for spreading firing.

Similar results were obtained in a series of tests to determine the best method of firing with Illinois coal conducted by the United States Geological Survey. Table IV exhibits these. (See Bul. No. 373 U. S. Geological Survey or Bul. No. 40 U. S. Bureau of Mines, page 146.

TABLE IV.

EFFECT OF METHOD OF FIRING.

U. S. G. S. Test No.	Method of Firing.	Firing Interval, minutes.	Black Smoke.	Efficiency.
			%	%
500, 504	Alternate	3.5	15.8	59.87
505	Alternate	3.4	14.9	60.20
503	Ribbon*	2.3	5.0	62.22
501	Spread	9.3	32.0	57.56
502	Coking	7.4	15.0	60.49

*Ribbon firing is a special type of alternate firing. In the test quoted the doors were fired alternately. This test shows a higher efficiency than any of the other methods and about 5% higher than the spreading method.

Firing Interval.

Authorities on steam boiler practice are united in the opinion that the operation of a boiler is improved by firing the coal in small quantities at short intervals of time. There is a limit to the short interval, however, which is reached when the inrush of cold air through the fire doors causes a loss which balances the gain due to better combustion and constant fire conditions.

There is no question but that firing "little and often" will do much towards preventing smoke. This is borne out by the results of Table IV. In this series of tests the amount of black smoke produced was approximately proportional to the firing interval. It was not possible to make any observations on this phase of the

question in the tests run at the Engineering Experiment Station because all the boilers in the power plant, including the one tested, discharge their smoke and gases into a common stack.

The data in Table IV indicates that the efficiency increases as the firing interval decreases. This is to be expected in the light of what has just been said about smoke prevention because smokeless firing is efficient firing unless smokelessness has been secured by admitting a very large amount of excess air.

The results of our tests collected in Table V show in a general way that short firing intervals are accompanied by higher efficiency when the alternate method of firing is used but not for the spreading method.

TABLE V.

EFFECT OF FIRING INTERVAL.

SPREADING.				ALTERNATE.			
Test No.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.	Test No.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.
			%				%
7	5.12	4.91	47.4	10	5.91	5.	53.1
12	5.	5.2	48.4	25	5.12	5.3	55.1
30	5.24	5.61	48.3	22	5.47	5.47	53.83
9	9.87	6.02	49.5	21	4.7	7.44	52.1
13	5.44	7.45	53.45	19	6.1	7.44	50.65
15	5.35	7.52	49.	20	6.	7.52	52.8
16	5.61	7.52	52.1	28	4.73	7.71	53.2
17	5.93	7.72	52.3				
11	5.6	9.48	55.3				
8	5.42	9.81	47.25				

Thickness of Fire and Clinker Troubles.

It was our intention to make tests to show the effect of different thickness of fire. The idea was abandoned after one test, No. 9. This test was made with a thick fire, averaging 9.87 inches, and so much trouble was experienced with clinker that the fire had to be cleaned twice in the 9½ hours run. This test clearly demonstrated

that the clinkering properties of this coal prevented its successful use with thick fires.

Thick fires are generally economical because the higher resistance to the passage of air through the grate and fire bed reduces the amount of excess air entering the furnace and thus increases the temperature of the fire and gases of combustion. In general these are conditions desirable for high efficiencies, but they are not desirable when the coal has a tendency to form clinker. The high temperature of the fire bed causes the ash to melt and fuse together. The result is a clinker.

A similar condition of affairs is shown in Tests Nos. 23 and 24. In these tests, although the fire was not thick, the draft over the fire was low, only about 1-10 inch of water. This resulted in a low air supply and a hot fire. A heavy clinker formed and the fire had to be cleaned twice during the ten hour tests.

In Test No. 30 an attempt was made to get the maximum capacity out of the boiler. The fire was forced too much and very bad clinker formed. The fire had to be cleaned twice and the capacity reached was not as high as in Test No. 10. In Test No. 30, however, the coal was very poor, being mostly slack and fine dust. More coal was fired than would burn and the fire varied from 4½ to 8 inches in thickness*. The average thickness was 5.6 inches. The principal difficulty in this test was that the fire was too thick for the fine coal which was being fired.

Tests Nos. 15 and 16 were also run with low draft, but in these cases the coal contained but little slack and the capacity developed was not large. These factors account for the absence of much clinker.

Wetting Coal.

Test No. 28 was made to determine the effect of wetting the coal upon the efficiency. Wetting the coal will often benefit clinker troubles by keeping the fire bed cooler. When fine coal is being fired wetting the coal sometimes serves as a kind of binder which holds the coal together and reduces the loss of good fuel through the grates. The results of Test No. 28 show a slight decrease in efficiency when compared with Tests Nos. 25 and 27, which are in the same group but which were run with a shorter firing interval. Test No. 28 should be compared also with Nos. 19, 20 and 21 in which the firing conditions are about the same, or with Nos. 15, 16 and 17, where the operating conditions are similar but which are fired by the spreading method instead of the alternate. These comparisons indicate that wetting the coal has but little effect upon the efficiency and that the heat lost in evaporating the water on the coal is balanced by decreased loss of fuel through the grate and by the

*This wide variation in fire thickness is accounted for by the fact that all other conditions were sacrificed to the endeavor to reach a high capacity with the poor coal. Ordinarily the fire was kept at practically constant thickness.

reduction of clinker troubles. It should be noticed that Test No. 28 required no cleaning and was sliced but twice. This is less than any of the other tests run at about the same time.

Test No. 6 was also run with a very wet coal which had been exposed to a heavy snow storm. This is not shown in the analysis of the coal because the glass jar holding the sample was accidentally cracked. The crack was not noticed and the sample dried out before the analysis was made. This test shows an equivalent evaporation per pound of coal as fired about 10% lower than other tests run under the same conditions.

The United States Geological Survey found that the boiler efficiency fell off about 1% for every 3% increase in the moisture in the coal.

In general it is important to keep coal dry and protected from the weather. Besides the loss in efficiency which often results from the use of wet coal, it is well known that wet coal, unless stored submerged under water, deteriorates more rapidly than coal which is kept dry and protected from the weather.

Cleaning.

The greatest improvement in the efficiency of the boiler appears when the effect of cleaning the boiler is invstigated. This is well shown in Table VI, by the tendency of the higher efficiencies to collect at the top of the table in the region up to 6 days after cleaning.

TABLE VI.

EFFECT OF CLEANING.

Test No.	Days after Cleaning.	Efficiency of Boiler & Grate.
25	1	55.1 %
11	3	55.3
18	4	58.1
22	6	53.83
7	6	47.4
12	7	48.4
28	8	55.3
13	8	53.45
8	8	47.25
9	9	49.5
10	10	53.1
19	10	50.65
15	10	49.0
20	11	52.8
16	12	52.1
21	11	52.1
17	13	52.3

It is to be noted that the efficiency for the first few days after cleaning is increased by 5% to 6% over the average of all the tests. This indicates the importance of frequent and thorough cleaning of the entire boiler.

In these tests the boiler was fed from a cold water supply through the injector. The cold water contains considerable scale forming material. In the intervals between tests the boiler was fed with hot water from the heating returns passed through feed-water heaters.

Geo. H. Barrus (Engineering Record, June 24, 1911, p. 690) describes two tests to show the effect of cleaning the heating surface of a boiler. The evaporation increased about 5% after cleaning.

Air Leakage in Setting.

Tests Nos. 22, 23 and 24 were made to determine the effect of air leakage in the setting. It is known that the setting itself is about as tight as any ordinary boiler setting in average condition. The leakage was increased by opening the 16″ x 16″ cleaning door in the rear of the setting about 4 inches on Test No. 23 and wide open on Test No. 24. For Test No. 22 this door was closed and the boiler operated under ordinary conditions. The same firing conditions were maintained for the three tests. The results are:

Test No. 22, door closed.........53.83% efficiency	10.1% CO_2
23, door open 4″.......46.6	8.1
24, door open wide.....43.1	6.9

These indicate the importance of making the setting as tight as possible. They also show that the percent of carbon dioxide in the flue gases is indicative of the amount of air leakage.

Firemen.

The fireman is by far the most important factor in securing higher boiler economy. A good fireman is careful and consciencious in the handling of his fire and studies his boiler and his fuel in an endeavor to get the largest possible evaporation per dollar's worth of coal fired. A good skillful fireman can undoubtedly increase the efficiency of the operation of a boiler by 10% to 15% over that secured by an indifferent and careless fireman. A really good fireman is not easily picked up and when one is secured it is well worth while to pay him enough to secure his interest and loyalty to the plant.

A series of tests described in the Engineering Magazine, Vol. 40, p. 83, shows this difference in firmen clearly. The boiler upon which the tests were made was equipped with a Hawley down-draft

furnace. One fireman fired large quantities of coal at long intervals and frequently threw coal on the lower grate. He claimed that he could not carry the load without this understoking. The second fireman fired small quantities of coal at frequent intervals. He worked the boiler carefully and did not resort to understoking, although he carried a larger load. The efficiency with the first fireman was 67.5% and with the second 81%. The 13.5% gain was due to careful attention and proper firing.

CO_2 Recorder.

Other things being equal a reasonably high percentage of carbon dioxide (about 14% for Missouri coals) is indicative of maximum efficiency. A good CO_2 recording instrument is of considerable value in showing combustion conditions and furnishes a guide for the fireman in handling his fire. This is illustrated by two tests recorded in Power, Dec. 8, 1908. The tests were of 24 hours duration on a 500 horsepower boiler equipped with a Roney automatic stoker, located in the plant of the Malden (Mass.) Electric Co. In the first test the CO_2 recorder was covered so that the fireman could not see it, in the second it was open for his inspection and guidance. The average results were:

Test No. 1. 7.7% CO_2; 59380 lbs. coal used. Equivalent evaporation, 9.9 lbs.

Test No. 2. 11.2% CO_2; 55955 lbs. coal used. Equivalent evaporation, 10.8 lbs.

A CO_2 recorder is a rather delicate instrument and must be carefully attended. In itself it has absolutely no effect upon the operation of the boiler, but if it is used to show what is happening in the furnace its indications may be made the foundation upon which a considerable increase in efficiency may be built.

Summary.

1. An increased use of Missouri coals would stimulate Missouri coal mines, improve their working conditions, decrease the cost of coal and increase the prosperity of the state.

2. Missouri coals, when properly handled, may be used with as high efficiency as any of the bituminous coals of the neighboring states.

3. Missouri coals are not harder to fire than other middle west bituminous coals.

4. The alternate method of firing gives slightly better results than the spreading method.

5. Short firing intervals are desirable with the alternate method of firing.

6. The thickness of the fire must be varied to suit the size of coal fired. For broken run-of-mine coal, under boilers similar to the one tested, the fire thickness should be about 5 or 6 inches.

7. Missouri coal tends to clinker when the excess air supply is low, when the boiler is forced, and when the fire is too thick.

8. Wetting the coal is sometimes successful in reducing clinker and the loss of unburned fuel through the grates. Otherwise it tends to reduce the efficiency.

9. It is highly important that the boiler be kept clean and free from scale and the tubes free from soot. Frequent cleaning and non-scaling water are well worth their cost.

10. Air leaks in the setting greatly reduce the efficiency. The setting should be carefully inspected periodically and all leaks repaired.

11. A careful fireman is a prime requisite for high efficiency and is worth higher wages than are usually paid.

12. A CO_2 recorder may be made a valuable guide to the fireman in handling his fire.

PART II.

GENERAL PRINCIPLES OF COMBUSTION AND BOILER OPERATION.

COAL.

Coal is a solid, opaque, combustible substance consisting mainly of carbon. It is found in layers or seams up to thirty or more feet in thickness in the upper crust of the earth. Coal mines are rarely deep mines. The average thickness of minable coal seams in Missouri is about 4 feet.

Coal is generally understood to be the remains of prehistoric forests of plants similar to those found in tropical countries today, but much larger and much more rapid in their growth. The refuse of these forests which fell to the ground collected for years and centuries until a thick layer, possibly hundreds of feet thick, was formed. Then, by some disturbance on the unstable surface of the earth, this layer of vegetable matter sank down and became covered with water, followed by the disposition of mud and sand which was brought to the sea by the rivers and covered the layer of vegetable matter deeper and deeper. Finally through the combined effects of time, pressure and heat the bed of vegetable matter became a seam of coal. In burning coal we burn the forests of prehistoric times.

Coals from different seams differ in their chemical and physical characteristics. This has caused the division of coal into several classes which have no well defined line of separation. These are:

Anthracite
Semi-anthracite
Semi-bituminous
Bituminous
Lignite.

Anthracite coal is the oldest coal formation. It is very hard, has a bright lustre and is not so dirty as bituminous coal. The common name, "hard coal", describes it well.

Semi-anthracite and semi-bituminous coal are coals which lie between anthracite and bituminous. They closely resemble one or the other of these two larger classes as their names suggest.

Bituminous or "soft" coal, is easily broken and shows a stratified structure clearly. The surface is usually dull, but a freshly broken piece shows some lustre. Bituminous coals often have thin white or bronze colored seams running through them. This is a deposit of earthy or mineral matter which forms ash when the coal is burned.

Lignite has a brown or black-brown color and is soft and easily broken. It often shows a vegetable structure and deteriorates rapidly when exposed to the action of the weather.

Missouri coals are all bituminous coals of about the same general characteristics as the coal of Illinois and the other Middle West coal producing states.

Coal consists of a combination of the following six substances:

Carbon
Hydrogen
Oxygen
Nitrogen
Sulphur
Ash

Carbon occurs in many different forms. Lamp black and soot are nearly pure carbon. Charcoal and coke are part of the carbon with the ash of wood and coal respectively. Carbon is the principal combustible material in coal.

Hydrogen, oxygen and nitrogen are gases. Hydrogen is the only one of them that is combustible. When it is supplied with the proper amount of oxygen it burns with a very hot, nearly colorless flame. The product of the union of hydrogen and oxygen in combustion is highly superheated steam and may be condensed into water.

Oxygen does not itself burn but must be supplied in order for any combustible substance to burn. For this reason it is called a "supporter of combustion."

Nitrogen will not unite with oxygen or other substances under ordinary conditions. It is said to be an inert gas. It forms about 79% of the total volume of the air, the remaining 21% being oxygen. There are a few other gases besides oxygen and nitrogen in the air, but their volume is so small that it is not considered. Nitrogen in coal is usually present in small amounts combined with other substances. The nitrogen in the air and that in the coal does not undergo any change in passing through the furnace and contributes nothing to the heat of combustion. It dilutes the oxygen and increases the total volume of the products of combustion.

Sulphur burns with a bluish flame. It does not occur free in the coal but is combined with other substances. Sulphur is regarded as undesirable in coal. It adds but little to the heating value and is usually thought to increase the tendency to form clinker.

Ash is the inert noncombustible material of coal.

In the "ultimate" analysis of a sample of coal, the amount of each of the six substances just described is determined and is expressed as a percentage of the total weight of the coal.

Coal is often described by the "proximate" analysis. This is much easier to make than the "ultimate" analysis. In this analysis the following four substances are determined and expressed as a percentage of the total weight of the coal:

Fixed carbon
Volatile matter
Moisture
Ash

Fixed carbon is carbon in a nearly pure form. It is the coke which a certain coal will produce minus the ash which is contained in the coke.

Volatile matter consists mainly of hydrocarbon compounds, that is, chemical combinations of carbon and hydrogen. It includes the gases of coal, like illuminating gas, together with tarry vapors and other similar substances.

Moisture and ash are self explanatory.

The method of making the proximate analysis is given briefly below.* It also illustrates the manner in which the various constituents in the coal behave when the coal is burned.

A sample of the coal is finely ground so as to pass a sieve with from 60 to 100 meshes per inch. One gram of this is accurately weighed in a crucible and then placed in a drying oven which is kept at a constant temperature slightly above the boiling point of water under atmsopheric pressure. After one hour the sample is removed, cooled and weighed again. The object of this operation is to drive off the moisture. The loss in weight before and after drying gives the weight of moisture in the one gram sample.

The same sample in a crucible with a loosely fitting cover is then placed over a Bunsen flame of a certain size and left for seven minutes, cooled and again weighed. While heated over this flame the volatile matter in the form of gases, tarry vapors, etc., are driven off and burn around the edges of the crucible cover. After weighing, the difference in weight before and after this operation is the amount of volatile matter. The time seven minutes with a definite size flame has been adopted as a standard, because by longer or shorter heating slightly greater and lesser amounts of the material in the coal would be distilled off as volatile matter. The term "volatile matter" is somewhat loose and there is no well defined point for separating the carbon in the volatile matter from the fixed carbon, except by such an arbitrarily chosen method as outlined.

*For more complete details see:
Journal of the American Chemical Society, Vol. XXI, No. 12, Dec, 1899. (Published by Chemical Publishing Co., Easton, Pa.)
Also, Technical Paper No. 8, United States Bureau of Mines. (Address "Director, Bureau of Mines, Washington, D. C."

What remains of the original sample is now the coke of the coal. It consists of the fixed carbon and the ash. The fixed carbon is determined by placing the coke sample uncovered over a very hot flame and leaving it there until only the ash remains. This may take several hours. Weighing again the difference in weight before and after burning out the fixed carbon gives its weight. The weight of the remaining ash is then known by subtracting the weight of the empty crucible from the weight of the crucible and the ash.

Summarizing, it is seen that coal is complex in its structure and consists of several chemical elements which may be collected into the substances determined by the proximate analysis.

(a) Moisture.

(b) Volatile matter, consisting of gases and tarry vapors; easily driven off when the coal is heated. It burns quickly.

(c) Fixed carbon, requiring a long time for its combustion.

(d) Ash, incombustible material.

The percent which each of these bear to the total weight of the coal is given in the proximate analysis. Sulphur is occasionally given also, but it is determined separately by an entirely different method.

The classification of coals is often based upon the amount of fixed carbon which they contain. This is not the best classification but it is the one most used.

	Percent of Fixed carbon in the Combustible*	Percent of Volatile Matter in the Combustible.
Anthracite	100 to 92.3	0 to 7.7
Semi-anthracite	92.3 to 87.5	7.7 to 12.5
Semi-bituminous	87.5 to 75.	12.5 to 25.
Bituminous	75. to 50.	25. to 50.
Lignite	50. to 0.	over 50.

Coal is mined in all sizes from large lumps to fine dust. This mixture of sizes just as it comes from the mine is known as "run-of-mine" coal. The run of mine coal is often passed over screens to separate it into different sizes before it is sold. The large lumps which pass over the screen are called "lump coal" and the fine stuff which passes through the screen is called "slack", "breeze" or "screenings". Sometimes an additional screen is used to separate out what is called "sized egg" or "nut" coal. The name suggests the size.

*By "combustible" is meant the combustible matter of the coal, i. e., the total coal minus the ash and moisture.

At some mines coal is graded according to the following table:

No. 1—Coal passing through	3	inch screen and over	1¾	in. screen
No. 2—Coal passing through	1¾	inch screen and over	1	in. screen
No. 3—Coal passing through	1	inch screen and over	¾	in. screen
No. 4—Coal passing through	¾	inch screen and over	¼	in. screen
No. 5—Coal passing through	¼	inch screen		

COMBUSTION.

Combustion is the rapid union of a substance with oxygen. Heat is given off in the process. The substance which burns, or with which the oxygen unites, is called "the combustible".

Carbon burns, or unites with oxygen, and the combustion may be complete or incomplete.

Complete combustion results when carbon is supplied with all the oxygen with which it can unite. This can be determined by definite laws of chemistry. When complete combustion of carbon takes place an inert, combustible gas, called carbon dioxide, is formed. This gas is sometimes represented by the chemical symbol CO_2.

If the oxygen supply for the carbon is deficient, incomplete combustion will take place. In this case a combustible gas, carbon monoxide (represented by the symbol CO) is evolved.

Heat is always given off when combustion occurs and the same amount of heat* is always generated when a given amount of the same substance is burned to the same completeness of combustion. Thus when one pound of pure carbon is burned completely to carbon dioxide (CO_2), 14500 B. t. u. are always given off. When one pound of pure carbon is burned to carbon monoxide (CO), 4400 B. t. u. are evolved. Furthermore, when the carbon monoxide resulting from the incomplete combustion of one pound of carbon is burned, the product of the combustion is carbon dioxide, and the heat evolved is 10100 B. t. u. Thus the same amount of heat is evolved, viz. 14500 B. t. u., when a pound of carbon is burned, whether the combustion proceeds directly to completeness or goes through two processes to completeness. If the combustion passes through two stages, however, and some of the carbon monoxide passes away unburned, the heat which it would furnish, at the rate of 10100 B. t. u. per pound of carbon, is lost.

The complete combustion† of one pound of hydrogen forms steam and about 62000 B. t. u. are given off.

*The unit of heat is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. This is called the "British Thermal Unit (B. t. u.)."

†The combustion of most of the substances occuring in coal except carbon is always complete.

The oxygen necessary for the combustion of coal in a furnace comes from the air. Air, being a mixture of oxygen and nitrogen in the proportion of 21% and 79% by volume respectively, supports combustion. The nitrogen of the air passes through the furnace without change. In boiler practice in order to be sure that sufficient air is provided it is necessary to supply somewhat more than just enough air to carry in exactly the amount of oxygen for the combustion. In the best practice only about 40% excess air is supplied, but in many plants the excess may be 200% and more.

The amount of carbon dioxide (CO_2) formed is always the same for the complete combustion of a given weight of carbon, no matter how much excess air is supplied. The per cent of carbon dioxide, or the volume of carbon dioxide compared with the total volumes of all the gases (CO_2, CO, hydro-carbons, air, nitrogen, etc.) leaving the furnace, becomes smaller as the amount of the other gases increase. This can be illustrated by the following example: Suppose a quart of milk and a quart of water are mixed together, the milk will then be one half, or 50% of the total mixture. Now increase the water to three quarts with one quart of milk. The actual amount of milk is the same but now it is only one fourth, or 25%, of the mixture. In the same way the percent of carbon dioxide, CO_2, in the gases leaving the furnace decreases as the amount of excess air increases.

When a shovel full of soft coal is thrown on a bed of hot incandescent fuel, the moisture and volatile gases are first driven off very rapidly, and in large volumes. The action is so rapid and the volumes of gas so large that there is but little opportunity for proper mixture with air for burning. Furthermore, some heat is necessary to warm up the coal and drive off the volatile matter, so that the process cools off the furnace. The volatile gases are the same as those driven off by the Bunsen burner in the proximate analysis. In order to thoroughly understand what occurs in the furnace it is necessary to study those volatile gases.

Experience with common illuminating coal gas, and also with producer gas, has shown that these gases contain a large amount of tar which must be removed before the gases can be used for light or in a gas engine. We should expect to find the same tar present in the volatile gases driven off in a boiler furnace.

An idea of the behavior of the tar in the furnace may be gained by pouring a little tar on a hot iron plate. A dense brown tarry smoke is given off. We know that this is probably not a gas for gases are usually transparent and invisible. It is hard to imagine that this smoke is made up of little solid particles. It is more probable that the color is given to the smoke by small particles of the

tar in a liquid or semi-liquid form, like the spray from an atomizer. It is quite easy to imagine tiny little globules of tar, small and light enough to be carried along with the gases. They are similar to the nicotine carried along with tobacco smoke, which may be caught as a deposit if the smoke is blown through a cloth.

The soot deposited on the tubes and that which passes out of the stack and blackens the surrounding neighborhood is evidence of little solid particles of unburned carbon.

Thus in the products passing out of the furnace we may expect to find volatile gases, liquids in the shape of small, round, tarry globules, and small solid particles of carbon. If all of the possible heat of the fuel is obtained all of these things must be completely burned.

There are three conditions necessary for the complete combustion of any substance:

1. A sufficient supply of oxygen, usually in the form of air.

2. The maintenance of a temperature above the ignition temperature of the substance to be burned.

3. A thorough mixture of the combustible with the oxygen or air so that every particle of the combustible may find the oxygen necessary for its combustion.

The first condition is easily obtained in boiler practice by adjusting the air supply with the dampers.

High temperature will follow when good combustion is secured provided the excess air is not too great.

A satisfactory mixture of air with some of the combustible material is the most difficult to obtain. With the true gases the mixture is comparatively easy because it is the nature of gases to diffuse readily and become intermingled into a homogeneous mixture. With the tar globules the problem is quite different and a good mixture is difficult to obtain.

Consider one of the tar globules as it is carried along in the current of gas. It travels at about the same rate as the gas stream so that there is but little tendency for the gases to rub past it or have any kind of scrubbing action upon it. The result is that after the outer layer of the globule is burnt it becomes surrounded by a blanket of inert gases. These do not have time to diffuse into the surrounding gas stream and are not scrubbed away by it so that they prevent further burning of the tar globule by keeping the necessary oxygen from coming into contact with it. The behavior of solid particles of carbon which are formed by the decomposition of some of the gases is quite similar to that of the tar globules, so that these two constitutents of the products of the furnace tend to

pass out of the stack incompletely burned. They appear as soot or smoke.

The principles of combustion and the effect of proper mixture and air supply may be illustrated by the common oil lamp.

If the chimney is removed black smoke is formed. This is caused both by the cooling effect of the large amount of air which has access to the flame and because the unconfined air and gases move at a low velocity and do not scrub away the burnt gases fast enough. If the chimney is replaced the air and gases inside the chimney are confined and move with much higher velocity and the flame is protected from the cooling effect of the outer air. The higher velocity of the gas inside the chimney scrubs off the burnt gases so that the air supply from the bottom of the chimney has easy access to the combusible gases. If the hand is placed over the openings at the base of the chimney so that the air supply is cut off, a smoky flame is again produced because the air supply is insufficient.

Going back to where the shovel full of coal was fired, it is found that the fixed carbon is left after the moisture and volatile matter is driven off. The fixed carbon burns as a bed of yellow or white hot coals upon the grate. Air passes up through the grate and burns the first or lower layers of carbon to carbon dioxide (CO_2). In the presence of very hot carbon and little air the carbon dioxide formed unites with carbon in its passage upward through the fuel bed and forms carbon monoxide (CO). This operation takes up heat, 10100 B. t. u. per pound of carbon. The carbon monoxide mixed with some unchanged carbon dioxide issues from the top of the fuel bed and if the carbon monoxide is supplied with air it will burn to carbon dioxide and return the 10100 B. t. u. previously taken up. The air for this combustion may be furnished over the top of the fuel bed or may come from excess air passing up through the grate.

Geo. H. Barrus (Engineering Record, June 24, 1911, p. 690) shows by two tests that an increase of 10% in the equivalent evaporation per pound of coal was obtained by admitting air over the fuel bed to burn the volatile gases and carbon monoxide.

One pound of average Missouri coal gives off about 12600 B. t. u. when it is fully consumed. In the ordinary plant only about 45% to 70% (averaging about 50% in the majority of the smaller plants) of this heat is present in the steam formed. That is, only about one-half of the coal supplied is actually used in making the steam, the other half supplying the losses. There are several of these losses and the majority of them are unavoidable.

1. There is a loss due to unconsumed fuel falling through the grate, or wasted by being pulled out with the clinker when cleaning

the fire. This is a direct loss of unconsumed fuel, but it is unavoidable, except that in many cases an excessive amount is carelessly pulled out in cleaning. This loss is small, usually in the neighborhood of 4% to 6%.

2. The loss due to the incomplete combustion of the carbon that burns to carbon monoxide amounts to as much as 3% to 4%. It can be eliminated by sufficient air supply and proper mixing.

3. The heat lost in evaporating the moisture in the coal may reach as high as 6% in some cases and is unavoidable, except that the percent of moisture in the coal can be reduced to a minimum by keeping the coal in a dry place.

4. There is a loss due to the moisture formed in burning hydrogen, amounting to about 5%. This is unavoidable.

5. Heat radiates from the setting and this loss amounts to some 2% to 5%. It is unavoidable but it can be reduced to a small extent by insulation of the walls of the setting. This is seldom practiced.

6. There is an avoidable loss in the unconsumed fuel which passes out of the furnace in the form of carbon particles and little tar globules and is directly seen as soot and smoke. This loss is often as large as 10% and nearly all of it can be prevented by proper air supply, proper firing and a thorough mixture of air with the volatile gases. The loss due to carbon particles or soot alone is probably 1% or 2%.

7. Another large and partially avoidable loss is that due to the heat carried away by the chimney gases. This loss amounts to as high as 40% in some boiler plants, but by careful manipulation and adjustment of the air supply it may be reduced to about 15% or 18%.

The last two of these losses are large and are the ones which can often be considerably reduced with a corresponding increase in the boiler efficiency.

The loss in the unconsumed fuel which passes out of the furnace with the volatile matter may be reduced in two ways:

First, from the description of the tar globules and their behavior it appears that if sufficient scrubbing action by the hot gases upon the envelop of inert gas surrounding the tar globules could be produced, the loss would be reduced because more of the tar would be burned. To increase the mixing and scrubbing action wing walls and mixing piers are used in the furnace. They tend to break up the stream of gas and form swirls and eddies. They are difficult to keep in repair because of the high temperature to which they are subjected. The second and better method is to prevent as far as possible, the formation of the tarry globules. This is what is accomplished by the use of automatic stokers and down draft furnaces.

In the stoker the coal moves into the furnace slowly and is gradually heated up. The process is not almost instantaneous as when a shovelful of coal is thrown on a hot bed of coals. As a result the gases are distilled off slowly instead of in great volumes all at once. Ample time is thus given for mixing with the air necessary for combustion. The distilled gases must pass over the hot fuel bed and be scrubbed by the hot air rising through it. The little tar globules are exposed to a high temperature longer and may even become gaseous and easily burned. An automatic stoker is coking firing and firing "little and often" reduced to the lowest possible limit.

Stokers have one further advantage in that the conditions inside the furnace are practically constant and uniform, instead of constantly and rapidly changing as in a hand fired furnace. Thus if the draft and air supply are once properly adjusted, they will continue to be correct until the feed of the stoker is changed.

Stokers reduce the boiler room labor costs in large plants but not in small plants.

The down draft furnace also serves to distill the volatile matter slowly.

An important factor in securing complete combustion of the volatile matter is in the use of tile roofs over the grate. If the gases strike a comparatively cool surface, such as the boiler shell or tubes, they are cooled below their ignition point and condensed into the tarry globules which are so hard to burn.

In the hand fired furnace, except the down draft type, it is difficult to prevent rapid distillation because the firing must necessarily be intermittent. Much can be done by breaking the coal into uniform pieces, about egg size, and by carefully scattering small charges of coal at frequent intervals. With small uniform sized lumps of coal the distillation is general instead of localized as is the case when large lumps are fired. In the latter case little opportunity is given for mixing and heating because the volume of the gas distilled at one place is so large.

Frequent firing well scattered gives an opportunity for mixing and approaches the operation of a stoker with continuous distillation.

The loss carried away as sensible heat in the flue gases can be reduced by reducing the temperature and weight of the flue gases. These gases act as a carrier of the heat from the furnace to the boiler. The boiler cannot remove or absorb any heat which exists as heat in the gases below the temperature of the boiler. Thus the gases must always carry off some heat up the stack. When reduced to a minimum this loss is necessary and unavoidable. It is necessary

because the hot chimney gases cause the draft which draws air into the furnace and it is unavoidable because it is impossible for the boiler to absorb the heat when the gases are at or near the temperature of the steam.

This loss will be a minimum when the weight of the flue gases multiplied by their absolute temperature is a minimum.

The direct cause of the extremely large loss found in the average small plant is due to the large amount of excess air supplied, for it is this alone that increases the weight of the gases. All the excess air, together with the nitrogen in the required air, is heated from the temperature of the fire room to that of the chimney gases. The heat to do this comes from the coal. The excess air may come through too thin a fire, holes in the fire or leaks in the setting.

The loss of heat from air leakage is apparent. Every fireman knows that if the fire doors are left open the pressure will begin to drop. He never leaves the doors open after firing if he expects to make steam.

It is quite an easy matter to cut down an excessive air supply. In many cases it will be found that the excess air is passing through holes in the fire. This may appear to be a trifling matter, but a few holes in a fire may together have the same area as the fire door. They then admit as much air as the fire door would if it were left open. If it is important to keep the fire doors closed it is just as important to watch the fire and keep the holes in it closed.

The amount of air which a setting, apparently in the best condition, will leak is surprising. The settings of the test boilers of the U. S. Geological Survey plant were kept in the very best condition. One of their bulletins states that one man was almost constantly employed for nothing else than patching air leaks and keeping the settings in good repair. Test results on these boilers showed an air leakage of about 26%, that is, about one-fourth as much air leaked through the setting as was supplied through the grates. It is quite probable that the leakage in ordinary settings is very large, possibly 50% to 70%.

In good practice about 40% excess air is required in order to have sufficient to insure good mixing. This corresponds to about 13% to 14% CO_2 in the flue gases for average Missouri bituminous coal. In many of the average smaller plants 200% or more excess air is admitted. The corresponding proportion of CO_2 is about 6%. The avoidable loss (waste) in such a case is about 10%.

Clinker.

Clinker is caused by the fusion, or melting and running together, of the ash left when coal is burned. It has been shown lately that the ash of different coals have different fusing temperatures. The

ash of one coal may fall through the grate unchanged because the temperature of the fire was too low to fuse it, while the ash of another coal under similar conditions may melt and run together to form a hard clinker. The ash with a high fusing temperature may partially melt and become soft so that a thick and pasty, but porous mass is formed which sticks together but still allows the passage of some air. Under similar conditions the ash of low fusing temperature melts and forms a sticky, semi-fluid mass which spreads out and runs over the entire grate, covering it with a thin vitreous clinker which effectually prevents the passage of air. This type of clinker covers a larger area than the other and does not admit even a small amount of air through it. It also tends to run down between the grate bars so that it is very difficult to remove.

When the fuel bed over the grate is cool very little clinker forms. This can be seen by watching the fire just after it is cleaned. At first there is no ash on the grate and the cold air rushing up through the bars, keeps the fuel bed near the grate cool. When the ash begins to collect and pack together the air passages are partially closed up and the cooling action reduced. As a result the temperature of the fuel bed near the grate increases. This tendency continues to increase as the amount of ash collected on the grate increases. Finally a point is reached where the ash fuses and clinker begins to form. Before this the coal burns freely and quickly upon the grate and it requires close attention to keep holes out of the fuel bed. As soon as the clinkers begin to form the coal does not burn so readily and the fire begins to increase in thickness.

Forcing the fire increases the temperature and therefore increases the tendency to form clinker, and the clinker formed is likely to be quite fluid so that it spreads over a large part of the grate area. If it is not removed it gradually reduces the air supply and causes the capacity to fall off because of the difficulty of burning the coal. A clinker of this kind is so soft that it is hard to handle when cleaning or slicing the fire.

The tendency to clinker can often be reduced by wetting the coal, the use of steam jets under the grate or water in the ash pit. All of these means have their effect by cooling down the fire. They all results in a direct loss of heat but sometimes make forcing possible under conditions and with fuel which would not otherwise allow it.

Fire Thickness.

The question is often asked, "What is the best and most economical thickness of fire?" No definite answer can be given because so many variable factors enter into the circumstances which control the best fire thickness.

One of the most important of these factors is the size of the coal used. If the coal is all fine slack the fire must be kept thin. The fine particles of coal pack together and tend to fill up the voids or interstices in the coal, making it difficult for the air to get through. If the fuel bed is thick it may not be possible for enough air to pass through to burn the coal. Only such coal as receives the necessary air will burn, so that a thick bed of fine coal will evaporate less water into steam than a thinner fire bed which allows the necessary air to pass through it. If the draft is increased more air will, of course, be drawn through the thick fuel bed, but the losses from the leakage of cold air through the setting are also increased.

With nearly uniform sized egg coal a thicker fire should be carried than with fine coal because the air easily passes through the larger crevices formed in the bed of larger fuel. In order to keep the excess air down to a reasonable amount it is necessary to make the fuel bed thicker so as to increase the resistance to the flow of air.

In general, the larger the lumps and the less slack in the coal, the greater the thickness of the fuel bed. On account of the difficulty of burning the large volumes of volatile matter set free, it is essential that large lumps be crushed. Lumps larger than a man's fist should not be fired. Besides the difficulty of imperfect combustion of the volatile matter, it is found that large lumps cause a fire to burn in holes. The air comes in around the edges of a lump and burns the surrounding small fuel faster than the lump. Soon a hole is left around the lump.

Up to a certain thickness, depending upon the size of the coal and the draft, a thick fire will give greater capacity because holes are less likely to form. A thin fire requires great regularity of firing and close attention to keep all holes covered. A thick fire is easier to fire and takes less attention, but the economy is likely to be lower. Thick fires are more subject to clinker troubles than thin ones. The draft as well as the size of the coal, is of importance in fixing the proper thickness of the fire. With a low draft, for any size coal, the fire bed must be thinner than with a high draft, because with low draft the resistance to the passage of air must be low. A high draft requires a thick fire to increase the air resistance and cut down the excess air.

Draft Capacity and Rate of Combustion.

In most plants the practice is to use all of the draft available. If the steam pressure rises too high, some firemen open the furnace doors, others close the flue damper, open the breeching door or close the ashpit doors.

The practice of opening the fire doors is very bad, first, because

it makes an increased loss due to the large amount of heat carried off by the air, and second, the cold air rushing in cools the boiler plate quickly and causes sudden contractions and temperature stresses. These weaken the plate and produce leaky seams.

Closing the stack damper or opening the breeching doors is to be preferred to closing the ashpit doors, because these do not cause an increase of air to be drawn in through the setting leaks as is the case with closing the ash pit doors.

For a large capacity, the rate of combustion must be increased, a larger amount of coal must be burned on the same grate, requiring more air and a good draft. When boilers must be forced particular attention should be paid to keeping the setting tight and free from leaks.

The rate of combustion depends directly on the intensity of the draft and the thickness of the fire. A thick fire is usually necessary when a large capacity is to be developed but thick fires do not burn coal with the best efficiency. Accompanying a thick fire there is likely to be a large loss due to incomplete combustion of carbon because the air supply is reduced to a minimum.

We found the maximum rate of combustion for the Missouri coal we tested to be about 25 or 30 pounds of coal per square foot of grate surface per hour, with a draft of about .6 inch of water at the stack damper. Even at this rate the fire was white hot and the clinker very soft. Much slicing and cleaning was necessary with a consequent large loss of combustible drawn out with the clinker. A lower rate of combustion would have given a better efficiency and less clinker trouble.

Too high a draft will cause the fine coal to be carried away from the fuel bed unburned. Even a draft of .15 inch of water over the fuel bed was found to carry fine particles over the bridge wall. In locomotive practice the draft is very high, compared with stationary practice, and large pieces of carbon, many one-fourth inch in diameter, are thrown out of the stack. Tests by the U. S. Geological Survey have shown the loss due to these cinders thrown out the stack to be in some cases as high as 5%, with run of mine coal, the draft being about 2½ inches of water over the fuel bed.

Too low a draft will cause a very hot fuel bed and consequently much trouble with clinker. It will be noticed that much the same effect is produced by reducing the draft or thickening the fuel bed as both decrease the air supply.

Cleaning and Slicing.

Fires are usually cleaned or sliced when there is sufficient clinker to cut off the air supply and reduce the capacity appreciably. If the clinker is rather thick, porous and easily broken, such as is

obtained by a slow rate of combustion, a slice bar can be run underneath the clinker and raised just high enough to break the clinker a little, shake some ash down and allow more air to pass through the fuel bed. In this operation care must be taken not to raise the slice bar through the fuel bed because the green coal, ash and hot fuel are then all mixed together. This increases clinker troubles, and produces a fire full of holes.

Sometimes a fire is in such a condition that the large clinker can be removed with the slice bar, but unless all of the clinker is removed and a thorough cleaning takes place, the fire is usually left mixed up and in very bad condition.

An attempt to slice a very hot fire where the clinker is in a pasty mass, usually ends in a bad fire with clinkers sticking to the grate. It may be necessary to let the fire cool somewhat before slicing.

The method of cleaning a fire by pulling the clinker out with a slice bar does not waste as much combustible but takes more time than the regular method. It cannot always be done on account of high temperature and soft clinker. The common method of cleaning described below is probably the best way to treat a fire which is not developing the required capacity, unless the clinker is porous and can be broken up by a careful slicing without disturbing the fuel bed.

In the ordinary method of cleaning enough fuel is fired to give a good bed of coals. After it has gotten well started the fuel on one side is thrown or "winged" over to the other side with a bar. Care should be taken to get all of the combustible away leaving only ash and clinker on the grate. This clinker bed is broken up by slipping the bar underneath and raising it up. The mass of clinker and ash is then pulled out of the fire door with a hoe into a barrow or on to the floor. The burning fuel is then scattered over the clean grate by placing the bar in the other door and throwing the fuel back, leaving only ash and clinker on the second side. The first side should now be fired in order to have a good live fire to scatter over the second side when the grate is clean. This will require a good heavy firing.

Before breaking up the second side it is well to let the fire burn a while to get a good start. If the clinker is very hot or sticky this wait after firing the first side allows the clinker to cool and it contracts and will not stick to the grates as badly as when it is hot.

The second side is then broken up and pulled through the fire door in the same way and the good burning fuel scattered over the clean grate as before. Both sides are then fired, completing the

operation. The doors should be open only when necessary and the cleaning done as quickly as possible.

The following method of cleaning fires is recommended by the Smoke Abatement Department of St. Louis. It has been successfully used in the University Power Plant, and when the directions are properly followed it produces less smoke than the ordinary method during the cleaning and immediately afterwards. It probably has very little effect upon the boiler and furnace efficiency:

"Do not clean out when fires are low, or when fresh fuel has just been added. Have a good bed of coal. Throw all the red fuel over on other side from one to be cleaned. Loosen up cinder with slice bar and pull out with hoe or rake. Break up coal to first size, and scatter four to six shovels on bare grates. Then throw hot coal back over fresh fuel on side that has been cleaned, and leave door ajar a minute or two. Wait for at least two firings before cleaning the second side, in the meantime firing somewhat heavier in front. See that the coal is incandescent, and proceed as with first side. Cleaning out in this manner will avoid making dense smoke, and will not lower the temperature of the boiler as much as the careless, usual way of cleaning fires."

Methods of Firing.

There are three methods of firing used in ordinary boiler practice, viz., **coking, spreading** and **alternate.**

In the **coking method,** after about all of the volatile matter is distilled off, the hot fixed carbon is pushed with a hoe to the back of the grate near the bridge wall. Here it makes a heap of bright, white-hot coals without smoke. Fresh coal is fired near the fire doors across the furnace, so that at all times the grate is covered with white hot coals at the back and green coal at the front.

The object sought for in this method is to distill the gases off of the green coal in front and to burn them while kept hot by passing over the hot bed of coals at the back. When the volatile gases are all driven off from the fresh coal in front leaving a bed of white hot coke, it is pushed back to replenish the hot bank in the rear and more fresh fuel is supplied at the front.

This method is seldom used in the Middle West. It is not an easy way of firing and is not suitable when large capacities are to be developed. It is often advised as a means of reducing smoke. There is a large loss of green fuel through the grates, and the frequent stirring of the fire tends to increase the clinker. The frequent opening of the fire doors increases the temperature stresses in the boiler and cools the furnace.

When this method of firing is used air should be admitted over

the grate to help burn the volatile gases distilled from the green fuel.

The **spreading method** is the most commonly used method. It does not require as good a fireman or as much attention as the coking method.

Depending upon the size of the grate, two to six shovelfuls of coal are fired at a time, scattering the coal evenly over the grate. The fire is kept nearly level, a little thicker at the sides and back.

The fireman is apt to fire too much at a time or to fail to scatter the coal. If the coal is not well scattered, but each shovelful falls in one large mass, the fire will be cooled and deadened in spots. This causes uneven burning and the formation of holes. Holes are most likely to form at the sides and especially near the bridge wall. Fresh coal should not be used to fill up holes, but the fire should be leveled with a wide hook. All lumps should be broken up. Care must be taken not to dig in the fuel bed and stir up the ash with the hot live coals because this will increase the tendency to form clinker.

A good method of scattering the coal after the bed is level is to begin a strip at the back and scatter the coal over the strip while working to the front. A little practice will enable a good fireman to scatter a shovel full from the back to the front. Several of these strips will cover the entire grate.

The **alternate method** is much the same as the spreading method except that about one-half of the grate is fired at a time. For example, in a long line of boilers, the fireman goes down the line firing the first, third, fifth, etc., doors the first time, then making a second trip to fire the second, fourth, sixth, etc. The plan of firing in strips applies here as well as in the spreading method.

Where a three door furnace is used, the front half of the first and third doors and the back half of the second door are fired at one time. Then the next time the back half of the first and third doors and the front half of the second door are fired.

It is important that the fire be watched carefully and fresh fuel fed promptly, because the coke beds are apt to burn down letting an excess of air through. The object in leaving the coked bed is the same as in the coking method, the hot coke helps to burn the gases distilled from the fresh coal. Holes should be kept covered and the fire about level as in the other method.

In both the spreading and alternate methods of firing particular attention should be given to the scattering or sprinkling of the fresh fuel. Many firemen do not give this point care enough and it is very important. The practice of throwing the coal on the fire in heaps and firing enough to last fifteen or twenty minutes cannot

be too severely condemned if high economy is desired. The fire is completely covered up and a dense cloud of smoke, indicating much unburned combustible, pours out of the chimney. Much of the fire is wasted and the firebed is left full of holes. If the coal is sprinkled over the fire, each lump separated from the others, the gases are exposed to the hot fuel bed and become well mixed with air. Good combustion then follows. In order to secure this result a few shovelsful frequently fired must be the rule. The importance of the length of time between firing has been mentioned in the first part of this bulletin. In general the shorter the firing interval the higher the efficiency and the less smoke. This is illustrated in Table IV, p. ...

The difference between a good and a poor fireman is usually due to the difference in the care and interest they have in their work, the difference in their skill in sprinkling the coal and keeping holes covered and in the frequent firing of small amounts of coal by the good fireman as compared to the fireman who piles in enough coal to last twenty minutes and then lets the fire burn full of holes.

Rules for Firing Using Illinois and Indiana Coal in Hand Fired Furnaces.

(Formulated by the Coal Stoking and Anti-Smoke Committee of the Illinois Coal Operator's Association.)

1. Break all lumps and do not throw any in furnace any larger than one's fist. The reason for this is, that large lumps do not ignite promptly and their presence also causes holes to form in the fire, which allow the passage of too much air.

2. Keep the ash pits bright at all times. If they become dark it is evident that the fire is getting dirty and needs cleaning, which, if not done, will cause imperfect combustion and smoke. If the furnace is equipped with a shaking grate, it should be opened often enough to prevent any accumulation of ashes in the fire. Do not allow ashes to collect in the ash pits, as they not only shut off the air supply, but may cause the grate to be burned.

3. In firing do not land the coal all in a heap, but spread it over as wide a space as possible as it leaves the shovel. A little practice will enable one to catch the proper motion to give the shovel to make the coal spread properly.

4. Place the fresh coal from the bridge wall forward to the dead plate and do not add more than three or four shovels at a charge. If this amount makes smoke it should be reduced till smoke ceases, which means, of course, that firing will be at more frequent intervals than formerly to keep up steam. This rule applies in cases

where the boiler is worked at a large capacity. In such instances, however, where a small capacity only is required, firing by the coking method is the best, wherein the fresh coal is placed at the front of the fire and pushed back and leveled when it has become coked.

5. Fire one side of the furnace at a time so that the other side containing a bright fire will ignite the volatile gases from the fresh charge.

6. Do not allow the fire to burn down well before charging. If this is done, it will not only result in a smoky chimney, but an irregular steam pressure.

7. Do not allow holes to form in the fire; should one form, fill it by leveling and not by a scoop full of coal. Keep the fire even and level at all times. As far as possible level the fire after the coal has become coked.

8. Carry as thick a fire as the draft will allow, but in deciding on the proper thickness, judgment must be exercised. If the draft is poor a thin fire will be in order, but if strong, a thicker fire should be carried.

9. Regulate the draft by the bottom or ash pit doors and not by the stack dampers, because when the stack damper is used it tends to cause a smoky chimney, as it reduces the draft, while the closing of the ash pit door diminishes the capacity to burn coal. If strict attention is given to firing, and according to demand for steam, there will be no occasion to have recourse to dampers, except where there is a sudden interruption in the amount of steam being used.

10. A good general rule is to fire little and often, rather than heavy and seldom. The former means economy in fuel and a clean chimney, while the latter signifies extravagance in fuel and a smoky chimney.

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A REPORT OF STEAM BOILER TRIALS UNDER OPERATING CONDITIONS

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INTRODUCTION.

Steam boiler trials may be divided broadly into two classes:

1. Tests under predetermined conditions, which are kept constant throughout, the purpose being to make a scientific study of the boiler performance under these conditions.

2. Tests performed under the every day operating conditions of the steam boiler plant.

Acceptance Tests.—These are made upon a new installation of boilers previous to their acceptance by the purchasers. They belong in class 1.

It is customary to include in a contract for steam boilers a number of clauses which carefully specify the minimum efficiency of combined boiler and grate when operating within a certain per cent of the rated power. Thus, it may be stated that, when burning bituminous mine run coal having a heating value of not less than 10,500 B. T. U. per pound, and operating between 80 and 120 per cent of the rated horsepower, the boiler shall absorb not less than 70 per cent of the calorific value of the coal.

In order to satisfy the purchaser that such a guarantee has been fulfilled, a boiler test must be made of not less than twelve hours duration. Commonly, the directions for the conduct of boiler trials comprised in the Standard Code of the American Society of Mechanical Engineers are followed. The boiler is fired up and operated for some time, in order to get the setting thoroughly heated up. Provision is made to dispose of surplus steam not needed in the operation of prime movers, so that the load, and all conditions, may be kept as nearly as possible constant. The firing is carefully supervised by the testing engineers representing the contractors and the purchasers. In some instances the coal is picked over and all slack and slaty coal thrown out. In short, every effort is made to get the best possible economy from the boiler on this test.

Tests Under Operating Conditions.—(Class 2). The conditions of every day service under which a boiler is operated are very different from those which obtain when an acceptance or similar test is run. Under every day operating conditions, the load on the boiler is likely to vary widely, from a very light load to a considerable overload, and sometimes these fluctuations follow each other rapidly. It is not practicable to maintain at all times the most advantageous test conditions.

The heating surfaces become coated with scale on one side and

soot on the other, with the effect of decreasing the rate of heat transmission from hot gasses on one side of the surface to water on the other. Brick work is liable to crack, permitting air leakage; and if this air becomes heated in the furnace, later passing off at the flue temperature, a loss of heat results. In addition to these reasons for a lower efficiency than can be obtained under special test conditions, mention should be made of what are called "stand-by" losses. An individual boiler in a plant may or may not be operated twenty-four hours a day. In the great majority of cases, the working day is much less than twenty-four hours. In electric lighting plants it may be a short period of a few hours carrying the plant over the peak load of the day. When a boiler is to be cut out the fire must be banked, an operation which takes a certain amount of coal. Furthermore, the boiler and setting begin at once to sool off, and the steam pressure falls. When the boiler is to be gotten under steam again, a considerable amount of coal must be burned to heat up the boiler and its setting before it can begin to produce steam. It is clear that coal thus burned during the stand-by period should be added to that burned while producing steam to get the total fuel cost. The proportion of this stand-by loss to the coal burned to evaporate water will depend upon the relative lengths of time the boiler is under steam and banked.

Let C = weight of coal burned to produce steam.
Let C' = coal burned during stand-by period.
Let W = total weight water evaporated.
Let w = pounds of water evaporated per pound of coal burned.

Then the number of pounds of water evaporated per pound is, properly

$$w = \frac{W}{C + C'}$$

If, however, C' is not considered, our expression would become

$$w = \frac{W}{C}$$

It is clear from the foregoing arguments, why the economy of a boiler, in pounds of feed water per pound of coal, based upon monthly records of coal burned and water fed to boiler, is bound to be much below the figure found by an acceptance or similar test.

The boiler tests which form the basis of this bulletin, the results of which are summarized in tables I, II, III and IV, were made from time to time by students, under the writer's direction in the course

of regular work in the Mechanical Laboratory at the University of Missouri. The boilers tested are located at the University heating and lighting plant, with the exception of the two tests of Table III, which were made on a Heine water tube boiler at the heating plant of the Horticultural Department.

The boiler equipment of the University heating and lighting plant consists of seven boilers, numbered consecutively, 1 to 7. Two of these, numbers 1 and 5, are Heine water tube boilers; the others are horizontal shell boilers of the return tubular type. Natural chimney draft is used for all. Boiler No. 1 is equipped with a rocking grate. The others have plain grates of the herring bone pattern. The tests herewith presented were made upon the two Heine boilers Nos. 1 and 5, return tubular boiler No. 7, and the Heine boiler before mentioned at the horticultural plant. The tests upon each boiler are comprised in a table, the short form of the A. S. M. E. Standard Code being followed. The heating surface, grate area, and rated power are given in each case.

In conducting these tests no effort was made to get an economy better than the ordinary daily performance. They represent ordinary operating conditions, but do not take into account stand-by losses.

The regular fireman fired the boiler in his customary manner. When the fire needed cleaning, he cleaned it, this operation usually taking place once or twice during the test. In case of the boilers with plain grates, most of the ash and refuse accumulates on the grate, and, in the process of cleaning, must be raked out through the door. This involves a considerable cooling of boiler and furnace, due to the admission of cold air, and a drop in the production of steam, disadvantages which are largely overcome by the use of a rocking grate, as in boiler No. 1. It was found in the tests on this boiler that nearly all the ash and refuse could be passed through by rocking the grate, though sometimes a few clinkers had to be raked out through the front door.

The method of starting and stopping was that defined in the Standard Code as the "Alternate Method." The procedure was as follows: The boiler being under steam, and the furnace and brickwork hot, the fire was burned low and cleaned. The pressure, temperatures, water level, and time of day were then noted, and the test was started. At the close the fire was burned low and cleaned, and the time of closing was considered to be the time when the operation of cleaning was concluded. An effort was made to have, as nearly as could be judgded from observation, the same amount of coal on the grate at the close as at the beginning. The water level in the boiler and the steam pressure were made the same as at the start.

The per cent of CO_2 in the flue gases was determined at frequent

intervals by means of an Orsat apparatus. The gas was drawn from a point in the flue between the boiler and damper, through a ¼-inch pipe, by means of an exhauster, and a sample was drawn off into the Orsat instrument from the side outlet of a tee in the gas line.

The feed water was weighed in two tanks mounted on scales in the usual manner, and discharged thence into a third tank from which the feed pump or injector used to feed the boiler took its supply.

At the end of each hour an hourly balance was determined of the quantity of coal burned and water fed to the boiler; the average pressures and temperatures for each hour were also computed. In connection with tables I and II the records of hourly quantities of five of the tests are graphically shown, Figs. 1 to 5. These indicate the variations in the boiler load that took place from hour to hour, as the demand for steam fluctuated.

It will be noted that the stand-by losses which occur when the boiler is cut out are not included in the tests. The final results indicate about what may be expected during the working period in the way of economy, in an ordinary plant of small size, equipped with boilers of from 125 to 250 horse-power, burning western bituminous coal, and hand fired by firemen of mediocre ability.

The efficiency of boiler and grate combined, item 31, ranges from 43 to 60 per cent. Disregarding tests No. 2, Table I, and No. 6, Table IV, the range of efficiency is 47 to 57 per cent. The average efficiencies for each boiler, including grate (item 31) are as follows:

Boiler No. 1,	Table I	46.1 per cent
" " "	Omitting Test No. 2	47.6 " "
" " 5,	Table II	51. " "
Hort. Boiler,	" III	48.5 " "
Boiler No. 7,	" IV	54.7 " "
" " "	Omitting Test No. 6	53.8 " "

For the purpose of estimating the fuel expenditure for a given quantity of feed water delivered to a boiler, items 24 and 25 are of practical value to the owner and operator of a steam power plant who has not at hand the means of readily determining the per cent of moisture and ash in the coal, and hence cannot figure down to the basis of dry coal and of combustible, as in items 26 and 27. The maximum, minimum and average values of items 24 and 25 are arranged in the following summary. Also, to reduce the fuel cost to the basis of dollars and cents, another item (No. 33 of the short form) is added, assuming that the cost of coal delivered to the boiler room is $2.50 per ton of 2,000 pounds.

	Boiler No. 1	Boiler No. 5	Hort. Boiler	Boiler No. 7
	1	1	1	
Item 24.—Water apparently evaporated under actual conditions per pound of coal as fired. Maximum values	5.38	6.04	5.77	5.92
Item 24.—Minimum value	5.08	5.47	5.36	5.07
Item 24.—Average of all	5.18	5.72	5.56	5.58
Item 25.—Equivalent exaporation from and at 212 deg. per lb. of coal as fired. Maximum values	5.74	6.50	6.30	6.98
Item 25.—Minimum values	5.32	6.07	5.78	5.86
Item 25.—Average of all	5.54	6.29	6.04	6.47
Item 33.—Cost of coal required for evaporating 1,000 pounds of water from and at 212 degrees, coal at $2.50 per ton. Maximum value	$.235	$.206	$.216	$.213
Item 33.—Minimum value	.218	.192	.198	.179
Item 33.—Average of all	.225	.198	.207	.193

TABLE I.

DATA AND RESULTS OF EVAPORATIVE TESTS.

Name and location of boiler: Heine boiler No. 1, at U. of M. Heating and Lighting Plant.

Kind of fuel: Illinois coal.

Kind of furnace: Rocking grate, hand fired.

Method of starting and stopping: Alternate.

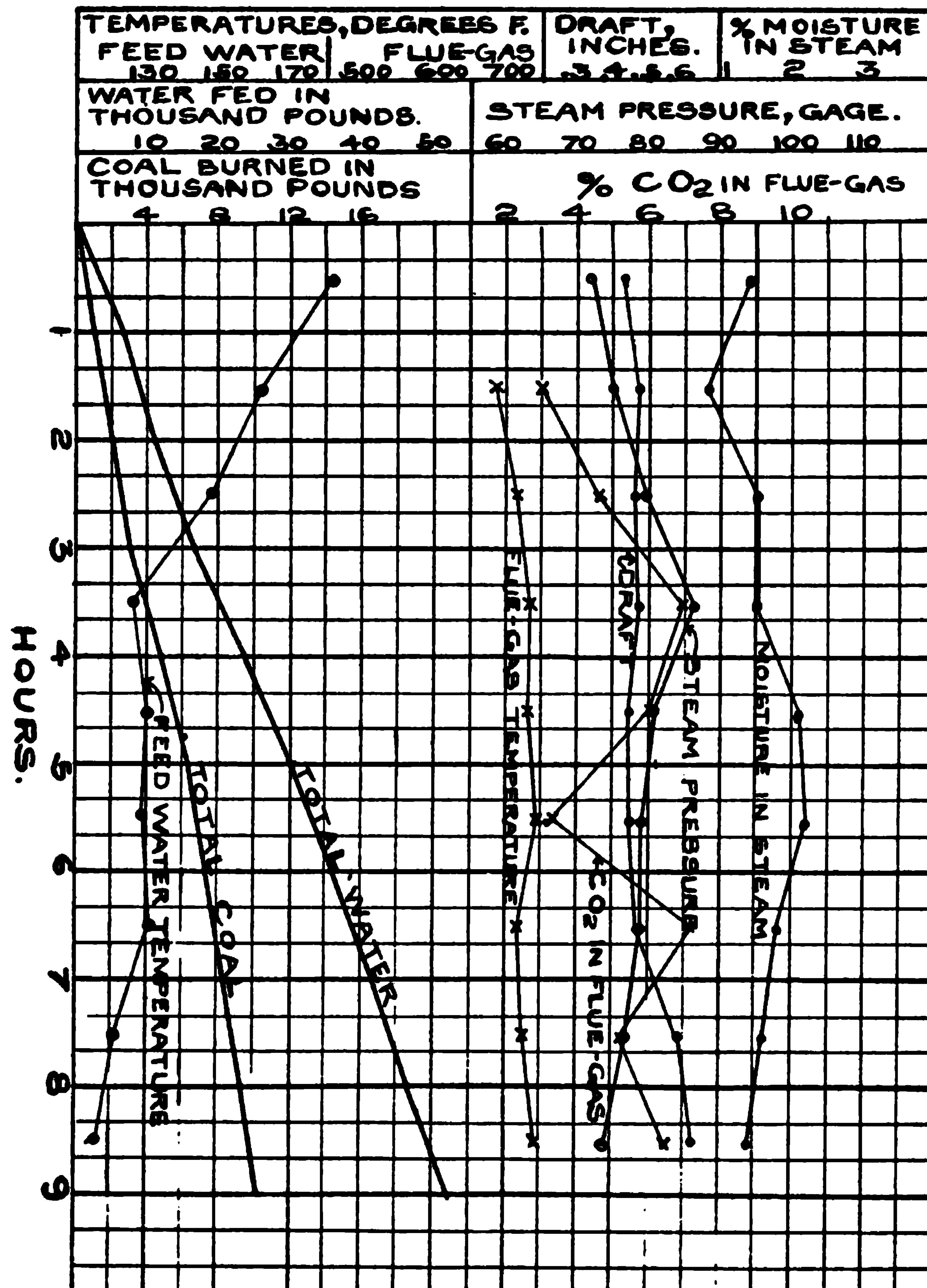
Grate surface: 40.5 square feet.

Water heating surface: 1399 square feet.

Total Quantities.	Test 1	Test 2	Test 3
1.—Date of trial	3/30, '12	4/13, '12	4/20, '12
2.—Duration of trial,hours	9	9.5	9.5
3.—Weight of coal as fired, pounds	10241	6200	6534
4.—Percentage of moisture in coal	9.52	8.32	6.98
5.—Total weight of dry coal consumed	9265	5685	6078
6.—Total ash and refuse, pounds	1588	685	838
7.—Percentage of ash and refuse in dry coal	17.15	12.3	13.7
8.—Total weight of water fed to the boiler, lbs.	52148	31482	35145
9.—Water actually evaporated, corrected for moisture in steam	51313	30850	34477
9a.—Factor of evaporation	1.110	1.069	1.087
10.—Equivalent water evaporated into dry steam from and at 212 degrees	56957	32980	37476
Hourly Quantities.			
11.—Dry coal consumed per hour, pounds	1029.5	599	639.7

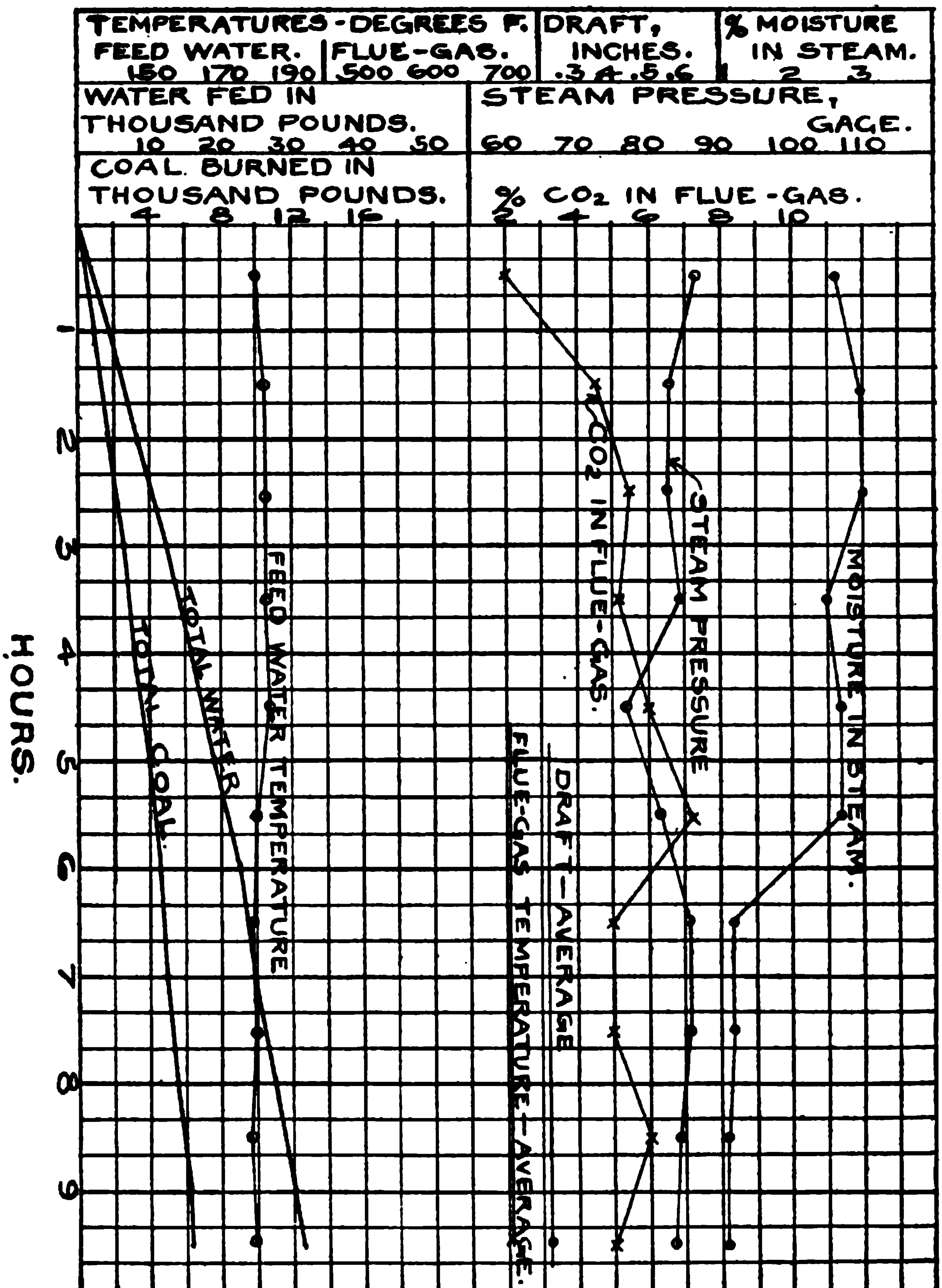
TABLE I.—Continued.

12.—Dry coal per sq. ft. grate surface per hour....	25.42	14.8	15.8
13.—Water evaporated per hour corrected for quality of steam	5700	3250	3629
14.—Equivalent evaporation per hour from and at 212 degrees	6329	3470	3944
15.—Equivalent evaporation per hour from at at 212 deg. per sq. ft. of water heating furnace..	4.52	2.48	2.82
Average Pressure and Temperatures.			
16.—Steam pressure by gage.......................	78.5	83.3	85.11
17.—Lemperature of feed water, deg. F............	138.5	181	163
18.—Temperature of escaping gas..................	726	705	702
19.—Force of draft between damper and boiler, inches of water.............................	.49	.22	.24
20.—Percentage of moisture in steam..............	1.6	2.0	1.9
Horse-Power.			
21.—Horse-power developed	183	100.7	114
22.—Builder's rated horse-power..................	150	150	150
23.—Percentage of rated power developed..........	122	66	76
Economic Results.			
24.—Water apparently evaporated under actual conditions per pound of coal as fired........	5.09	5.08	5.38
25.—Equivalent evaporation from and at 212 degrees per pound of coal as fired...........	5.56	5.32	5.74
26.—Equivalent evaporation from and at 212 degrees per pound of dry coal...............	6.15	5.80	6.17
27.—Equivalent evaporation from and at 212 degrees per pound of combustible.............	7.43	6.59	7.13
Efficiency.			
28.—Calorific value of the dry coal per pound, B. T. U.	12750	12940	12360
29.—Calorific value of the combustible per pound, B. T. U.	14390	14760	14750
30.—Efficiency of boiler based on combustible.....	50.1	43.15	47.0
31.—Efficiency of boiler, including grate, based on dry coal	46.8	43.25	48.4



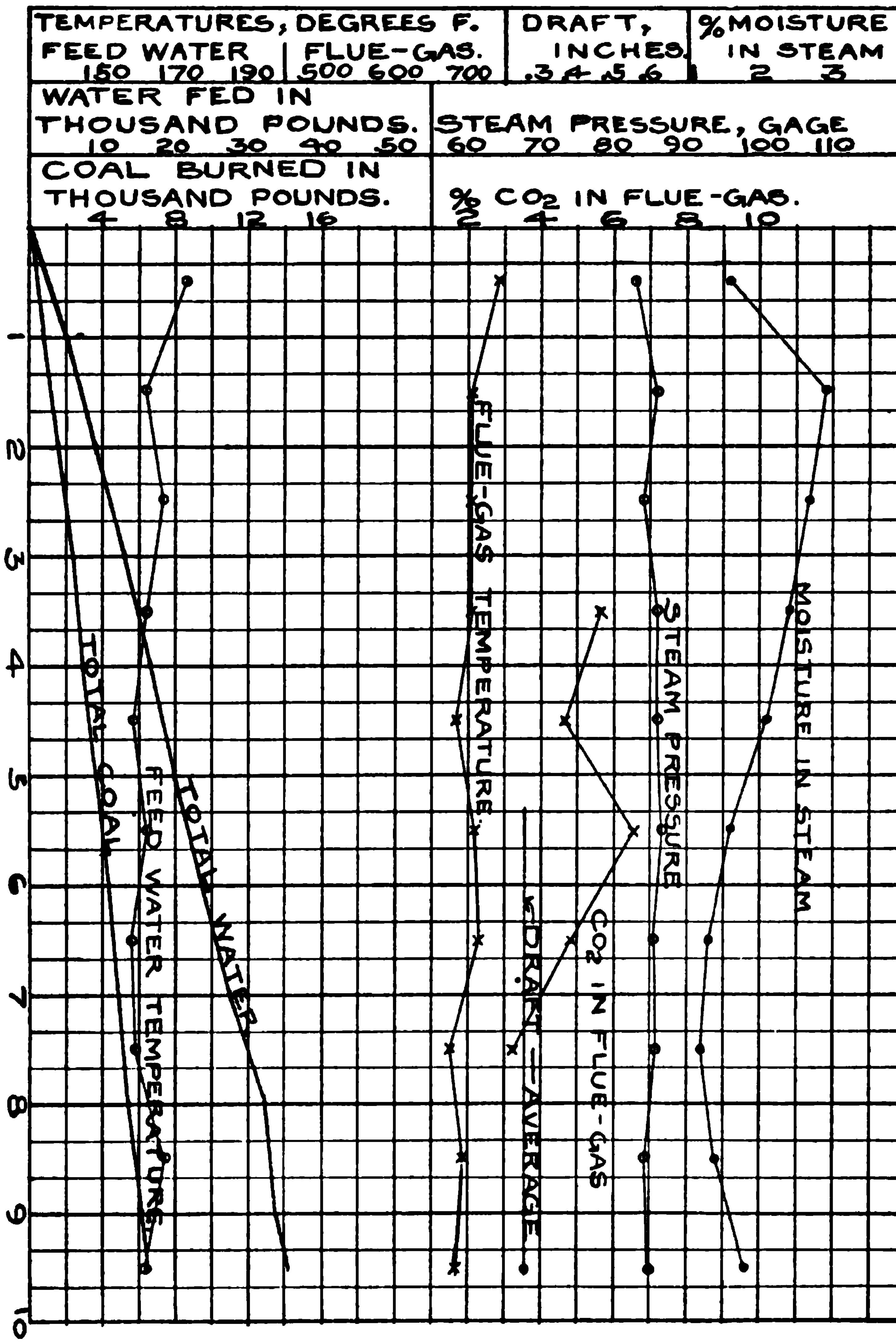
HEINE BOILER No. 1 — TEST No. 1

FIG. 1



HEINE BOILER No. 1-TEST No. 2

FIG. 2



HEINE BOILER, No. 1 — TEST No. 3

FIG. 3

TABLE II.

DATA AND RESULTS OF EVAPORATIVE TESTS.

Name and location of boiler: Heine boiler No. 5, U. of M. Heating and Lighting Plant.

Kind of fuel: Illinois coal.

Kind of furnace: Plain grate, hand fired.

Method of starting and stopping: Alternate.

Grate surface: 47 square feet.

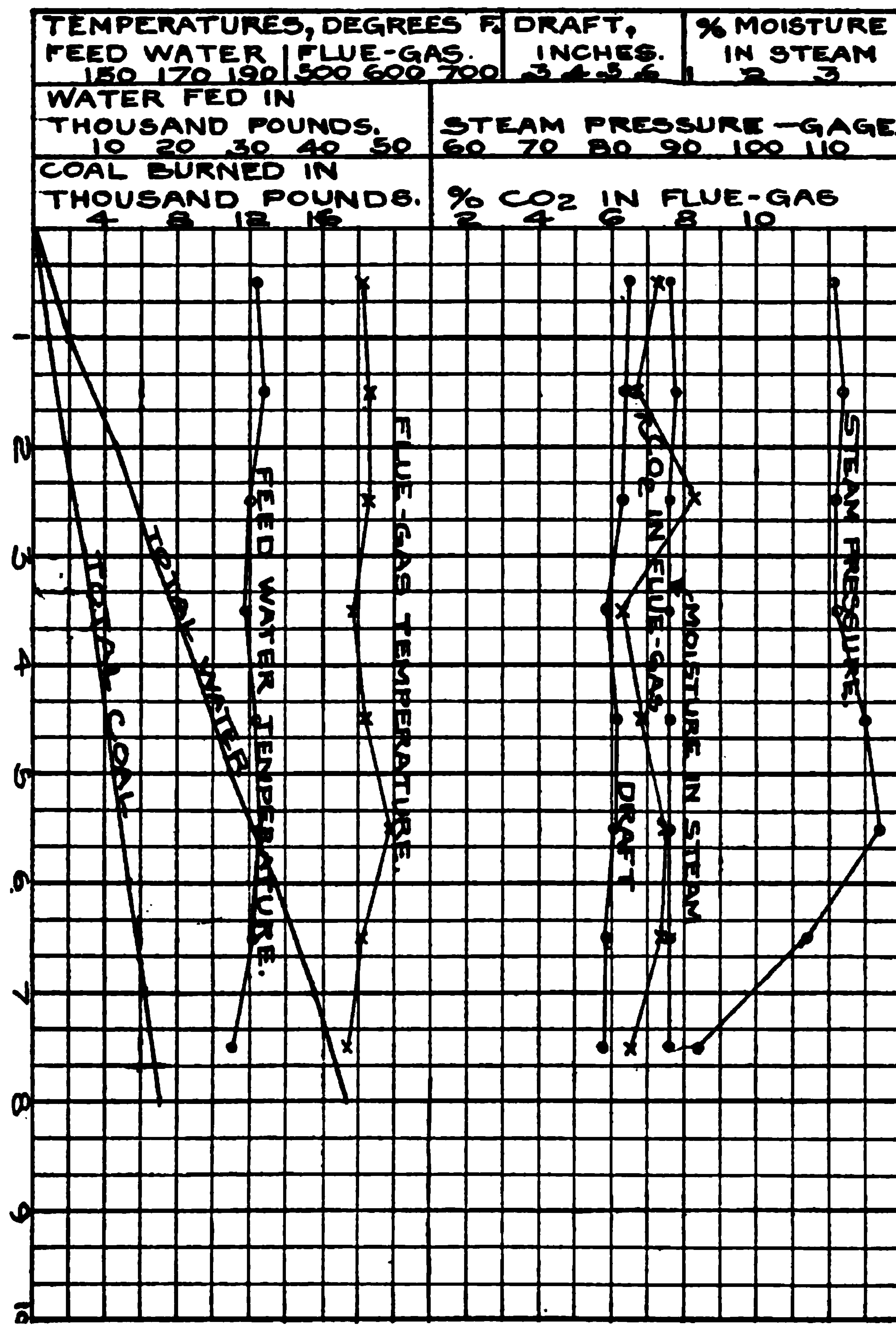
Water heating surface: 2232 square feet

Total Quantities	Test 1	Test 2	Test 3	Test 4	Test 5
1.—Date of trial	5/5, '09	5/6, '09	5/9, '10	4/27, '12	5/4, '12
2.—Duration of trial, hours	8	8	8	8	10
3.—Weight of coal as fired, lbs.	7429	8121	9682	7183	9727
4.—Percentage of moisture in coal	7.4	11.0	9.6	5.97	7.84
5.—Total weight of dry coal consumed	6879	7227	8752	6754	8965
6.—Total ash and refuse, lbs.	1143	816	1564	966.5	1199
7.—Percentage of ash and refuse in dry coal	16.65	11.3	17.9	14.3	13.4
8.—Total weight of water fed to the boiler, pounds	43912	45202	53000	43390	54504
9.—Water actually evaporated, corrected for moisture in steam	43692	44730	52310	43043	53926
9a.—Factor of evaporation	1.107	1.130	1.121	1.061	1.138
10.—Equivalent water evaporated into dry steam from and at 212 degrees	48367	50545	58640	45670	61368
Hourly Quantities.					
11.—Dry coal consumed per hour, pounds	859	903	1094	844	896.5
12.—Dry coal per sq. ft. grate surface per hour, pounds	18.26	19.22	23.2	18.0	19.06
13.—Water evaporated per hour, corrected for quality of steam	5461	5591	6540	5380	5392
14.—Equivalent evaporation per hour from and at 212 deg.	6046	6318	7330	5709	6137
15.—Equivalent evaporation per hour from and at 212 deg. per sq. ft. of water heating surface	2.70	2.82	3.28	2.40	2.74
Average Pressures and Temperatures.					
16.—Steam pressure by gage	84	92.5	95.8	109.5	108.7
17.—Temperature of feed water,					

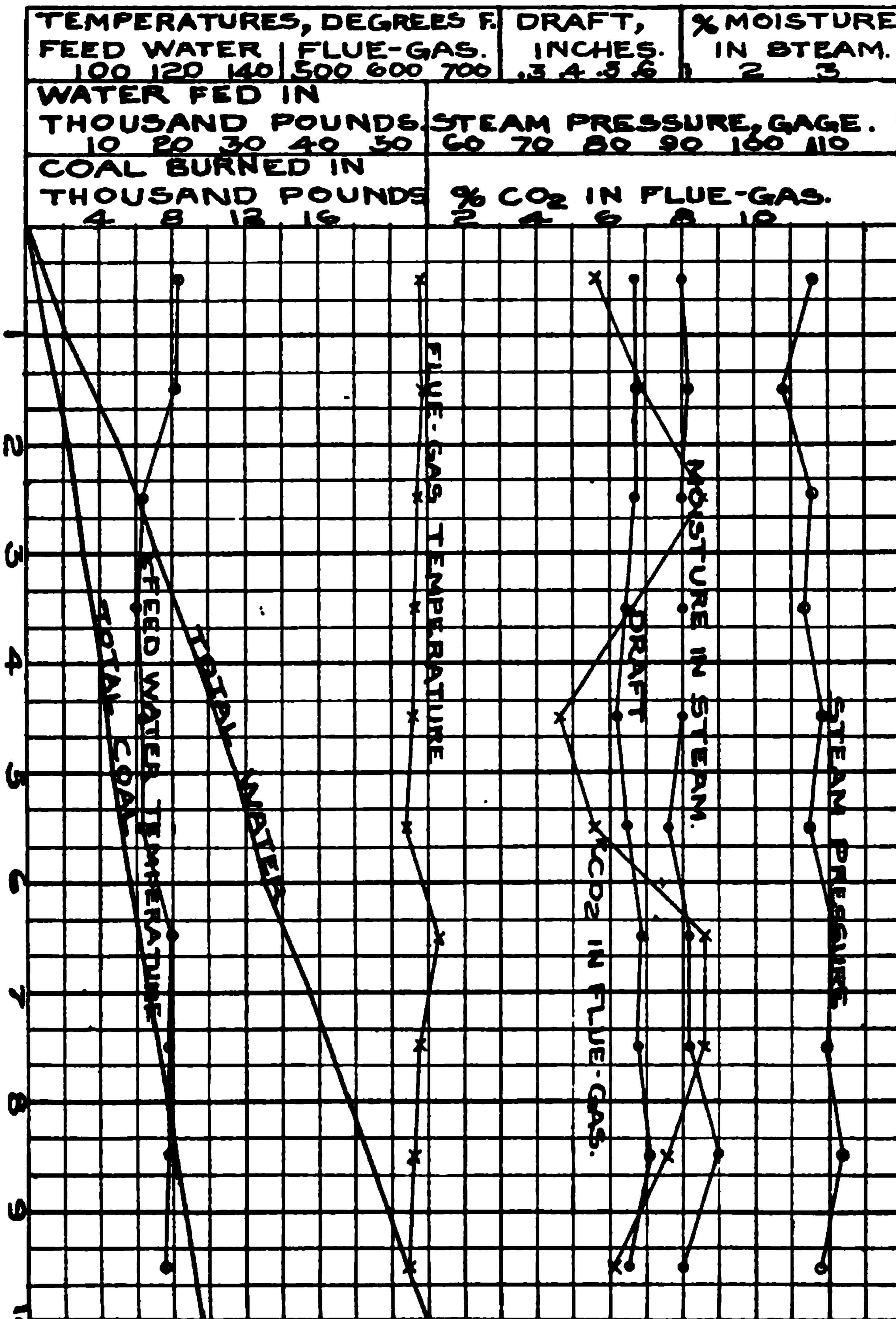
TABLE II.—Continued.

deg. F.	144	123	132	192	117
18.—Temperature of escaping gas.	515	512	609	563	637
19.—Force of draft between damper and boiler, inches of water	.42	.54	.67	.54	.57
20.—Percentage of moisture in steam	.49	1.05	1.30	.80	1.06
Horse-Power.					
21.—Horse-power developed	175	184	212	165	178
22.—Builder's rated horse-power.	250	250	250	250	250
23.—Percentage or rated power developed	70	73.6	84.8	66	71
Economic Results.					
24.—Water apparently evaporated under actual conditions per pound of coal as fired....	5.92	5.57	5.47	6.04	5.6
25.—Equivalent exaporation from and at 212 deg. per pound of coal as fired...........	6.50	6.23	6.07	6.35	6.28
26.—Equivalent evaporation from and at 212 deg. per pound of dry coal..............	7.04	7.00	6.70	6.76	6.84
27.—Equivalent evaporation from and at 212 deg. per pound of combustible	8.43	7.89	8.17	7.88	7.90
Efficiency.					
28.—Calorific value of dry coal per pound, B. T. U.......	13970	*13900	12520	12413	12616
29.—Calorific value of the combustible per pound........	14700	......	14570	14000	14450
30.—Efficiency of boiler based on combustible	55.6	......	54.5	54.6	53.1
31.—Efficiency of boiler, including grate, based on dry coal..	48.9	48.8	52.0	52.8	52.6

*Assumed.



HEINE BOILER No. 5—TEST No. 4
FIG. 4.



HEINE BOILER No. 5—TEST No. 5.

FIG. 5.

TABLE III.

DATA AND RESULTS OF EVAPORATIVE TESTS.

Name and location of boiler: Heine boiler at Horticultural heating plant.
Kind of fuel: Illinois coal.
Kind of furnace: Plain grate, hand fired.
Method of starting and stopping: Alternate.
Grate surface: 25 square feet.
Water heating surface: 1217 square feet.

Total Quantities.	Test 1	Test 2
1.—Date of trial	2/19, '10	2/22, '10
2.—Duration of trial, hours	9	10
3.—Weight of coal, as fired, pounds	4647	5100
4.—Percentage of moisture in coal	7.9	7.9
5.—Total weight of dry coal consumed	4280	4700
6.—Total ash and refuse, pounds	1068	1031
7.—Percentage of ash and refuse in dry coal	24.9	21.9
8.—Total weight of water fed to the boiler, pounds	26769	27355
9.—Water actually evaporated, corrected for moisture in steam	26582	27000
9a.—Factor of evaporation	1.096	1.090
10.—Equivalent water evaporated into dry steam from and at 212 degrees	29181	29421
Hourly Quantities.		
11.—Dry coal consumed per hour, pounds	475	470
12.—Dry coal per square foot grate surface per hour	19.0	18.8
13.—Water evaporated per hour, corrected for quality of steam	2955	2700
14.—Equivalent evaporation per hour from and at 212 deg.	3242	2942
15.—Equivalent evaporation per hour from and at 212 deg. per square foot of water heating surface	2.64	2.43
Average Pressures and Temperatures		
16.—Steam pressure by gage	44	65.3
17.—Temperature of feed water, deg. F.	144	156
18.—Temperature of escaping gas	574	646
19.—Force of draft between damper and boiler, inches of water	.34	.38
20.—Percentage of moisture in steam	.70	1.3
Horse-Power.		
21.—Horse-power developed	94	84
22.—Builder's rated horse-power	130	130
23.—Percentage of rated power developed	72.5	64.8
Economic Results.		
24.—Water apparently evaporated under actual conditions per pound of coal as fired	5.77	5.36

TABLE III.—Continued.

25.—Equivalent evaporation from and at 212 deg. per pound of coal as fired	6.30	5.78
26.—Equivalent evaporation from and at 212 deg. per pound of dry coal	6.82	6.26
27.—Equivalent evaporation from and at 212 deg. per pound of combustible	9.06	8.03
Efficiency.		
28.—Calorific value of dry coal per pound, B. T. U.	13184	12880
29.—Calorific value of combustible per pound	......	......
30.—Efficiency of boiler based on combustible	......	......
31.—Efficiency of boiler, including grate, based on dry coal	50.0	47.1

TABLE IV.

DATA AND RESULTS OF EVAPORATIVE TESTS.

Name and location of boiler: Return tubular, No. 7, U. of M. heating and lighting plant.
Kind of fuel: Illinois coal.
Kind of furnace: Plain grate, hand fired.
Method of starting and stopping: Alternate.
Grate surface: 25.3 square feet.
Water heating surface: 1239 square feet.

Total Quantities.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
1.—Date of trial	2/11, '11	2/25, '11	3/11, '11	4/1, '11	4/8, '11	4/22, '11
2.—Duration of trial, hours	10	9	10.23	10.06	10	10
3.—Weight of coal as fired, pounds	7957	8446	7658	8125	7379	7640
4.—Percentage of moisture in coal	9.0	12.0	8.4	9.4	8.9	9.5
5.—Total weight of dry coal consumed	7240	7430	7015	7360	6720	6914
6.—Total ash and refuse, pounds	1120	1348	1135	1128	1093	1157
7.—Percentage of ash and refuse in dry coal	15.5	18.1	16.2	15.3	16.2	16.8
8.—Total weight of water fed to the boiler, pounds	46506	42866	42313	44706	43673	40950
9.—Water actually exaporated, corrected for moisture in steam	45395	42350	42059	44350	43200	40377
9a.—Factor of evaporation	1.188	1.170	1.164	1.191	1.193	1.192
10.—Equivalent water evaporated into dry steam from and at 212 degrees	53923	49549	48956	52820	51537	48129
Hourly Quantities.						
11.—Dry coal consumed per hour, pounds	724	825	685	731	672	691
12.—Dry coal per sq. ft. grate surface per hour	28.5	32.5	27.1	28.8	26.6	27.2
13.—Water evaporated per hour, corrected for quality of steam	4539	4705	4110	4408	4320	4038
14.—Equivalent evaporation per hour from and at 212 degrees	5392	5506	4785	5250	5154	4813
15.—Equivalent evaporation per hour from and at 212 deg. per sq. ft. of water heating surface	4.35	4.44	3.86	4.23	4.16	3.88

TABLE IV.—Continued.

Average pressures and Temperatures.						
16.—Steam pressure by gage	93.6	90.4	96.7	94.8	92.2	96.7
17.—Temperature of feed water, deg. F.	67	83	90	64	62	63
18.—Temperature of escaping gas	560	547	522	472	521	485
19.—Force of draft between damper and boiler, inches of water	.73	.50	.46	.54	.53	.56
20.—Percentage of moisture in steam	2.4	1.2	.6	.8	1.1	1.4
Horse-Power.						
21.—Horse-power developed	156	160	139	152	150	140
22.—Builder's rated horse-power	150	150	150	150	150	150
23.—Percentage of rated power developed	104	106.6	92.6	101.3	100	93.3
Economic Results.						
24.—Water apparently evaporated under actual conditions per pound of coal as fired	5.84	5.07	5.52	5.50	5.90	5.36
25.—Equivalent evaporation from and at 212 deg. per pound of coal as fired	6.77	5.86	6.39	6.51	6.98	6.30
26.—Equivalent evaporation from and at 212 deg. per pound of dry coal	7.44	6.67	6.97	7.18	7.67	6.97
27.—Equivalent evaporation from and at 212 deg. per pound of combustion	8.81	8.16	8.32	8.47	9.16	8.38
Efficiency.						
28.—Calorific value of dry coal per pound, B. T. U.	12840	13190	12800	*13000	*13000	11380
29.—Calorific value of the combustible per pound	14600	14800	14350	15100	14750	14070
30.—Efficiency of boiler based on combustible	58.5	53.5	56.2	54.3	60.2	58.0
31.—Efficiency of boiler including grate, based on dry coal	56.2	49.1	52.8	53.7	57.2	59.6

*Assumed.

It will be noted that the boiler efficiencies in these tests are somewhat lower than those commonly found in similar boilers under test conditions. At the Louisiana Purchase Exposition in 1904 a large number of tests were made at the coal testing plant that was operated for the purpose of investigating the qualities of the various coals and lignites of the United States, the results of which are found in the published "Report on the Operations of the Coal Testing Plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, 1904." Heine Saftey boilers of 210 horse-power rated capacity were used. The grates were plain, the furnace hand fired and the draft natural. For purposes of comparison, the results of tests Nos. 18, 19, 38, 48, 50, 73, in which series Illinois coal was burned, are summarized, together with the tests of Table II, Heine boiler No. 5, in Table No. V, which follows. The data of the St. Louis tests are taken from the Report, p. 961. It will be note dthat the economic results, items 26 and 27, from Table No. II, are about 9 per cent less in amount than the corresponding figures for the St. Louis tests; while the two efficiencies, items 30 and 31, are respectively 10 and 14 per cent lower.

TABLE V.

A comparison of Economic Results and Efficiencies between Heine boiler No. 5, Table II, and tests made at the Louisiana Purchase Exposition, St. Louis. Illinois coal used in both series.

		Economic Results.				Efficiency (per cent).			
	Test Number.	Water apparanently evaporated under actual conditions per pound of coal as fired.	Equivalent evaporation from and at 212 deg. per pound of coal as fired.	Equivalent evaporation from and at 212 deg. per pound of dry coal.	Equivalent evaporation from and at 212 deg. per pound of Combustible.	Calorific value of dry coal per pound, B. T. U.	Calorific value of the combustible per pound, B. T. U.	Efficiency of boiler based on combustible.	Efficiency of boiler including grate, based on dry coal.
		24	25	26	27	28	29	30	31
St. Louis Tests.	18	5.54	6.51	7.21	8.76	11,855	14,252	59.36	58.73
	19	6.09	7.16	8.00	8.92	12,569	14,159	60.83	61.47
	38	6.19	7.35	8.04	9.53	12,857	14,712	62.42	60.39
	48	5.39	6.38	7.37	8.61	12,427	14,323	58.05	57.27
	50	5.34	6.36	7.27	8.44	12,439	14,319	56.92	56.35
	73	5.32	6.43	7.40	8.75	11,594	13,992	60.39	61.64
	Average	5.56	6.70	7.55	8.84	12,293	14,293	59.66	59.31
Table No. II.	1	5.92	6.50	7.04	8.43	13,970	14,700	55.60	48.90
	2	5.57	6.23	7.00	7.89	13,900	......	....	48.80
	3	5.47	6.07	6.71	8.17	12,520	14,570	54.50	52.00
	4	6.04	6.35	6.76	7.88	12,413	14,000	54.60	52.80
	5	5.60	6.28	6.84	7.90	12,616	14,450	53.10	52.60
	Average	5.72	6.28	6.87	8.05	13,084	14,430	53.56	51.02

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H. B. SHAW
Dean of the School of Engineering

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ECONOMICS OF RURAL DISTRIBUTION OF ELECTRIC POWER

BY

L. E. HILDEBRAND

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
March, 1913

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1st, 1909.

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PREFACE.

This bulletin is intended to be of interest to three classes of people; farmers, central station managers and engineers concerned with rural distribution of electric power. While all parts may not be clear to all three classes yet it is believed that the bulletin as a whole will be well understood by all if the few technical discussions are assumed to be correct. The entire paper is primarily a discussion of the economic problems of rural distribution rather than a handbook of rural electrical construction and practice.

We have, in the preparation of the manuscript, freely consulted the various technical periodicals and the reports of the various engineering societies. Much valuable information has been obtained from the **Electrical World, The Electrical Review and Western Electrician, The Proceedings of the American Institute of Electrical Engineers** and the **Proceedings of the National Electric Light Association.** Various text books of electrical engineering such as Sheldon, Mason & Hausmann's **Alternating Current Machines,** Franklin & Esty's **Elements of Electrical Engineering,** Steinmetz's **Alternating Current Phenomena,** Foster's **Electrical Engineering Pocket Book;** and the catalogues and bulletins of General Electric Company, Westinghouse Electric & Manufacturing Company, Western Electric Company, American Steel & Wire Company, and Central Electric Company, have been freely used.

We wish to thank Messrs. M. P. Weinbach, E. W. Kellogg and S. M. Hardaway for valuable assistance in correcting the manuscript and for general advice.

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University of Missouri,
Columbia, Missouri,
December 18, 1912.

INTRODUCTION.

Within the past few years there has developed a persistent desire in the mind of the American farmer for the conveniences of urban life. Throughout the country we find many instances of the gratification of this desire in the extended use of the comforts which a few years ago were considered luxuries on a farm. The rural mail delivery connects the farm daily with the entire outside world; the telephone keeps the farm continuously in touch with the immediate community while good roads promote both the business interests and the social intercourse of the rural population. The present large use of these and many other conveniences has made rural life more desirable and has lessened the migration of our farmers, and farmers' sons and daughters to the cities. At the present time we find everywhere the idea that city comforts should be brought to the farmer and not the farmer to the city conveniences.

Electricity on the Farm.—Among the various sources of comfort and convenience to be found in large towns and cities is the use of electricity for lighting, household purposes and power. The use of electric power in rural districts can and should be extended largely as it is a direct means of effecting a large saving of both money and time. Farmers realize the necessity of using labor saving devices. This more than any other factor has caused the large increase in the use of gasoline engines on farms. This bulletin is a discussion of a substitute for the gasoline engine which is as cheap if not cheaper than the engine, everything considered. It is not intended to depreciate the usefulness of a gasoline engine as it is indeed almost indispensible in some places, but rather to show a better means of obtaining mechanical power.

There is no doubt but that wherever possible it is generally preferable to employ power to do a certain task rather than to use manual labor. There are few at the present time who deny that electric power is the safest, most convenient and most economical means of doing work, if the electric power is obtainable at a fair price, but obtaining the power is often the stumbling block in the way of using electricity in rural regions. It must be shown that its conveniences and economy are so great that it would be wise, economical and expedient to distribute electricity for lighting and power to the rural districts.

Advantages of Electricity for Lighting.—Except those engaged in the sale of gas or gas-lighting fixtures, few deny that the electric

incandescent lamp is the safest and most convenient means of illuminating residences that has yet been discovered. This statement is confirmed by its extensive use in all cities where electric power is obtainable. How many times have you seen advertisements for hotels, apartment houses and residences for rent, which state as an added inducement, "Electric Lights" or "Thoroughly wired for electric light"? The number of large buildings without electric light is extremely small and most of the smaller ones have complete equipments if electricity is obtainable at a reasonable rate.

There are a number of desirable qualities possessed by the electric light which are not to be found with any other illuminant. When a house is wired in accordance with the present standards, the fire risk can be considered as negligible, whereas with any lamp which depends on an open flame for its incandescence and a match for its ignition there is always some danger of fire. The number of fires caused by matches which are not extinguished when thrown away, possibly on a carpeted floor or in a waste basket, is certainly large. The danger of an accident with the ordinary portable kerosene lamp is especially large. Electric light is safest and most convenient since it is only necessary to turn a switch to instantly flood the room with light. The electric light is not dirty and requires extremely little attention. Contrast this with any other known source of light and the relative merits of the different illuminants are easily seen. Since the electric lamp operates in a closed bulb and very little heat is thrown off, it is easy to see that, in winter when the rooms are more or less closed, the ventilation will be much better, and in summer the rooms will be cooler. There are other advantages, too numerous to mention in this paper, which make electric lighting universal where power is obtainable.

Household Use of Electricity.—There are many operations in the daily routine of housekeeping in which a small amount of power conveniently applied would be very advantageous. A small motor can be used to operate the washing machine or the sewing machine, to clean the room by means of a vacuum cleaner, to pump water, to clean and polish the silverware and even to wash the dishes. These tasks and many others which can be easily and expeditiously performed by electric power, are the ones which keep the housekeeper busy from morning until night, whereas, if a small motor is used, some leisure time is afforded for relaxation and the actual labor is made very much lighter. The electric flat iron is in daily use in thousands of homes, making ironing day very much less disagreeable. There are many electric heating and cooking devices on the market which find appreciative users in all parts of the coun-

try. A few of these devices are coffee percolators, toasters, chafing dishes, frying pans, ovens, curling irons, water heaters, shaving mugs, small heaters for halls and bathrooms, and glue pots. Some of these would undoubtedly be useful in rural homes.

Farm Motors.—A large motor can be used by the farmer in many operations which now require manual labor or the use of a gasoline engine. Grinding feed, cutting ensilage, pumping water for live stock or for irrigating during drouth, sawing wood, baling hay, threshing and many other tasks of similar nature are easily, quickly and cheaply accomplished by the use of an electric motor.

The farmer will say at once, "Can not all these things be done with a gasoline engine?" They can, but a motor possesses many advantages over the engines usually found on a farm. It is no trouble to start a motor—just close a switch and the machine is in operation. We all know the amount of trouble and exertion required to start a gasoline engine, especially in cold weather. If a motor is used there is no cooling water to attend to or to keep from freezing and no dangerous supply of gasoline is required which will be constantly wasted by evaporation. Ignition troubles are entirely absent. The first cost of a motor is lower than that of a high class engine and the yearly repair bills are very much less. A motor is always ready to give reliable and steady service at any time and at large overloads with high efficiency, whereas an engine must be in first class condition to deliver even its normal full load rating. Less space is required for a motor than for an engine. Insurance is always high on any building containing a gasoline engine while the proper installation of a motor will not affect the rates. A motor continues to give satisfactory, reliable and cheap service, with only a small supply of oil a few times a year long after two engines have been discarded. The popularity of the motor is due particularly to its cheapness but mostly to its ease of application, operation and control.

This comparison is not made to show the faults of the gasoline engine, but rather to show the many good qualities possessed by electric motors. Gasoline engines can not be recommended too highly for farm use where electric service is not available. Any task which an electric motor can perform, can also be done by an engine, but with less convenience, more trouble and, quite often, greater expense. If the advantages of using a gasoline engine on the farm are admitted, it follows that an electric motor would be even more advantageous.

Costs of Farm Operations.—Table 1 gives the cost of performing many farm operations with electric power at various rates. The

TABLE 1

Operation	Remarks
Grinding corn	Large grinder, about 40 bu. per hour
Grinding corn	Small grinder, about 10 bu. per hour
Threshing barley	
Cutting ensilage	6 tons per hr. cut and elevated with blower
Husking	4 bu. per hr.
Grinding feed	one ton per hr. of heavy grains
Shredding fodder	2 tons per hr.
Clover cutting	41 lbs. per hr. finely cut—90 coans
Milking	30 qts. per hr.
Corn sheller	26.5 bu. per hr.
Washing	1/8 hp. motor per washer full
Sawing wood	4 cords per hr.
Pumping water	72 gallons per hr.
Threshing rye, wheat, oats, barley	
Washing	1/4 hp. motor per washer full
Shredding and husking corn.	6 wall 3 header and husker
Vacuum cleaner	per 100 sq. ft. carpet or rug
Horse groom	1 hp. motor
Cream separator	
Butter churn and worker	
Sausage grinder	large
Sausage stuffer	3/8 hp. motor
Beet and turnip cutter	6 tons per hr.
Rolling oats	25 hp. mill
Cracking corn	
Oat crusher	
Milking	

figures are from various sources, most of them being obtained from tests under actual operating conditions, the results of which have been published in the several engineering magazines and reports of the engineering societies. No attempt has been made to substantiate these results except to give them a superficial examination. They are not intended to be used for the calculation of costs with any and all types of machines on the market, but rather to give a fair idea of the cost of doing some farm tasks with electric power.

TABLE 1

Unit	KW hrs.	Cents per Unit at following cost of power in cents per K. W. hour.						
		4	5	6	8	10	15	20
bu.	.4	1.6	2.	2.4	3.2	4.	6.	8.
bu.	.8	3.2	4.	4.8	6.4	8.	12.	16.
bu.	.125	.5	.625	.75	1.	1.25	1.875	2.5
ton	.66	2.64	3.3	3.96	5.28	6.6	9.9	13.2
bu.	.105	.42	.525	.63	.84	1.05	15.75	2.1
100 lbs.	.66	2.64	3.3	3.96	5.28	6.6	9.9	13.2
ton	5.5	22.	27.5	33.	44.	55.	82.5	110.
100 lbs.	.87	3.48	4.35	5.22	6.96	8.7	13.05	17.4
qt.	.004	.016	.02	.024	.032	.04	.06	.08
bu.	.028	.112	.14	.168	.224	.28	.32	.64
.. ..	.023	.092	.115	.138	.184	.23	.345	.46
cord	1.25	5.	6.25	7.5	10.	12.5	18.75	25.
hr.	.5	2.	2.5	3.	4.	5.	7.5	10.
bu.	.22	.88	1.1	1.32	1.76	2.2	3.3	4.4
.. ..	.061	.244	.305	.366	.488	.61	.915	1.22
tons	5.37	21.48	26.85	32.22	42.96	53.7	70.55	107.4
.. ..	.023	.092	.115	.138	.184	.23	.345	.46
horse	.106	.424	.53	.636	.848	1.06	1.59	2.12
100 lbs.	.04	.16	.2	.24	.32	.4	.6	.8
lb.	.0006	.0024	.003	.0036	.0048	.006	.009	.012
100 lbs.	.44	1.76	.22	.264	.342	4.4	6.6	8.8
100 lbs.	.05	.2	.25	.3	.4	.5	.75	1.
ton	.158	.632	.79	.948	1.264	1.58	2.37	3.16
bu.	.06	.24	.3	.36	.48	.6	.9	1.2
bu.	.1	.4	.5	.6	.8	.1	1.5	2.
bu.	.2	.8	1.	1.2	1.6	2.	3.	4.
can	.02	.08	.1	.12	.16	.2	.3	.4

The cost of energy for motor service on most farms will be between 4 and 8 cents per kilowatt hour, so these are the figures which should be taken for comparison in most places. Only the actual cost of energy is considered and all such charges as interest, depreciation, repair and taxes are omitted. This is the basis on which such work is usually compared.

Motors for general farm use are quite often mounted on skids or trucks so that they can be moved from place to place easily. The truck should have mounted on it not only the motor, but also a switch, a fuse for each wire and any starting device which is required. Fig. 1 shows a small motor mounted on skids with its

Fig. 1.

fuses and switch on a small upright board. Fig. 2 shows a large motor placed on a truck. If the motor is large enough to require a starting device it can be placed just behind the small switchboard.

Development of Rural Use of Electricity.—Within the past few years we find a remarkable development in the use of electricity in rural districts for both light and power. The progress has proceeded most rapidly in the more thickly settled communities in the states of the Mississippi valley. However, there is a greater aggregate of power used in the arid western states. In the central states, electric power is already used for performing almost every operation of farm life which requires power, while large tracts of land in the western states are made productive by irrigation with electrically driven pumps when otherwise they would be sandy wastes. Ohio, Illinois, Michigan and Indiana have numerous installations of transmission lines serving rural districts. Some western water power plants depend to a large extent for their income upon the power sold to ranchers for irrigation purposes.

The development has proceeded even further in European districts. In Italy and Germany are to be found many interesting

installations, the power even being used for tilling the fields very much as we use a steam or gasoline traction engine. A complicated construction is used to deliver electric power to the tractor through a system of cables. The system used is very expensive, but the results obtained more than compensate for the expense, so that the use of electric power is made economical even in the complicated system used for tillage. If this use of electric power has proved economical when we take into account the difficulties and the elaborate apparatus required, how much more would the use of electric power for stationary machines with very simple installations, prove advantageous? Americans have boasted of progressiveness for so long that we are rather inclined to believe that we are first in all things, but here is one matter in which Europeans are far ahead of us. These countries are more densely populated than the United States in the rural districts; this accounts for some of our lack of development. American rural communities are now rapidly improving in this respect and many farms where the work is done by the efficient electric motor are to be found. When the great convenience of the electric power and the service which the motor will give at a cost lower in most cases than that of other kinds of power which are available to farmers are considered, we can predict great progress in the use of electric power on farms during the next few years. All engineering magazines have articles on this subject from time to time, and central station managers are beginning to consider this field seriously as a means of extending their business. In fact there are few power systems in the western states which do not have considerable load consisting of motors connected to pumps for irrigation purposes; and a few derive the major portion of their income from farming communities.

Reasons for Development.—In the early days of electric power the more densely populated districts of large cities were the first markets to be developed, as a greater number of customers could be reached with little capital. As there were plenty of customers to be found in cities, the greater effort was exerted to obtain those from whom the largest profit could be derived with the least investment. Now that nearly all of the people of this class who will ever use electricity are already paying customers, an effort is being made to secure those customers from whom a fair profit can be derived, but who are harder to serve. One class of these customers is composed of factory power users, who are hard to serve because they require reliable and continuous power at a very low rate. Another class consists of those customers who are users of but little energy, and who are far from the central plant.

The remoteness of farmers from stations has kept the develop-

ment of rural distribution of electric energy in the rear for some time, but now that the possibilities of the large field for extension with prospects of fair returns is realized, more effort is being made to secure these many thousands of customers who were once thought to be entirely outside the zone of practical and economic distribution.

That it is both possible and profitable for central electric stations to extend service to at least some of the farmers can be seen

Fig. 3.

by considering the fact that a large number of "off peak" customers can be served from a relatively cheap line with voltages very seldom above 6600. It is the fact that the farmers will furnish a good day motor load which makes them particularly desirable customers.

It should not be hard for the farmer to see the desirability of using electric power when the many advantages and the low cost are considered. The central station man will see the advantages of serving these customers in those cases where the cost of construction of the line can be kept low enough to make the distribution of a small amount of power at a low unit cost profitable to the station. We shall therefore proceed to investigate the distribution of power in farming districts keeping before us at all times the economic side of the question.

Securing Electric Power on Farms.—Electric power can be made available in almost any rural district, but it is not always economical or practical to use electric power, especially in very thinly settled communities, and where each customer uses a very small amount of power. Most cases will need the exercise of considerable judgment to secure the best and most economical installation when more than one type of installation is feasible. In other cases it will require much consideration to determine whether or not an installation of any type is feasible. The various localities, having materially different conditions, necessarily present entirely different problems for solution. The amount of power used, meas-

ured in kilowatt hours per year per mile of line, is a factor in the selection of the system. Thus if there are four customers per mile, and each customer uses 2000 kilowatt hours per year there would be 8000 kilowatt hours sold every year for each mile of line. Under these conditions it might be feasible for a central electric power plant to install a distribution system; whereas if the customers are so far apart that only 1000 kilowatt-hours would be sold per year for each mile of line it would be impracticable to install a transmission line. In the case of a few isolated customers each one of whom use a fair amount of power, a separate plant for each farm is necessary.

Thus it appears that there are two sources of electric power for the farmer: first, isolated plants, and second, distribution systems from central electric plants. The former usually consists of a small generator driven by an internal combustion engine, continuity of service being obtained by the use of a storage battery to deliver stored energy when the engine and generator are not in operation. The second source includes distribution lines built from the near by plants, either by the cooperation of the farmers, or by the station itself; distribution lines supplied from high voltage transmission lines; and distribution lines from centrally located power plants for farmers only, such as are found in Germany. Each of these different phases of the problem will be studied separately in different parts of this bulletin.

Isolated Plants.—When a farmer desires electric service and when he is the only one in the community who wishes to use electric power, the isolated plant is the only solution, unless he is able to furnish an extremely large load. In the case of the isolated plant, a gasoline or oil engine is used to drive a small direct current generator which charges a storage battery, the energy for lighting and power being taken from the battery, or the battery and generator combined. Power can be obtained from the battery at all times, while the plant need be operated only occasionally for a few hours at a time. The number of hours that it will be necessary to use the engine and generator will of course depend entirely on the amount of energy that is used, as the battery has only a limited capacity, and must be charged frequently by the generator. This installation is suitable for supplying a small amount of power only, and is best adapted to lighting and household use, although power motors may be used if desired.

Most installations of this character use a one or two horsepower engine, with a one-half or one-kilowatt generator, and a storage battery which will store sufficient energy to light from 10 to 25 tungsten lamps, of 16 candle power each, continuously for 8

hours. If fewer lamps are used the battery charge will last longer. Therefore the average farm house can be lighted from three to seven days without the engine being used. A three horsepower motor can be used about two hours on the larger plant taking its power from the engine and battery together, but the power which can be used continuously is less than that of the engine, in most cases only about one-half, because it is only the stored energy in the battery which makes it possible to use the large motor even for a short time. The small isolated plant is intended to be used only for lighting purposes. There is little advantage in using a gasoline engine to drive a generator which would in turn operate the motor, when the engine itself could be used to drive the machine, obtaining more power for the same expenditure by eliminating the losses in the transmission line and motor. If an isolated plant is to be installed, a portable engine should be purchased so that it can be used for other power work, and the electric power be used for lighting only. There is no doubt that an isolated plant will give satisfactory service if a reasonable amount of attention is given to it, but the cost is liable to be very high for the service rendered. The operating expenses are seldom excessive, but the fixed charges such as interest on the investment and depreciation of the machine make the overall expense high. From the standpoint of cost, an isolated plant compares favorably with the other means of obtaining light on the farm, such as acetylene or gasoline outfits, and about the same amount of attention is required for satisfactory operation. However electric light has several advantages which make it more desirable. No system therefore, can be recommended in preference to the others, but the cost and service rendered by each must be considered in every case.

A Typical Isolated Plant.—As an example of what may be expected from isolated plant installations we give two examples of typical plants. The first plant described is a small one for lighting only, while the second is larger and has some advantages not included in the first. Figure 3 shows the general appearance of the small outfit while figure 4 shows a diagram of electrical connections.

The initial cost of the apparatus is approximately as follows:

Switchboard	$ 65.00
Engine, 1 horsepower	90.00
Generator ½ kilowatt at 50 volts	85.00
Belt, foundation, piping, etc	25.00
Battery 40 ampere hour, 16 cells	85.00
	$350.00

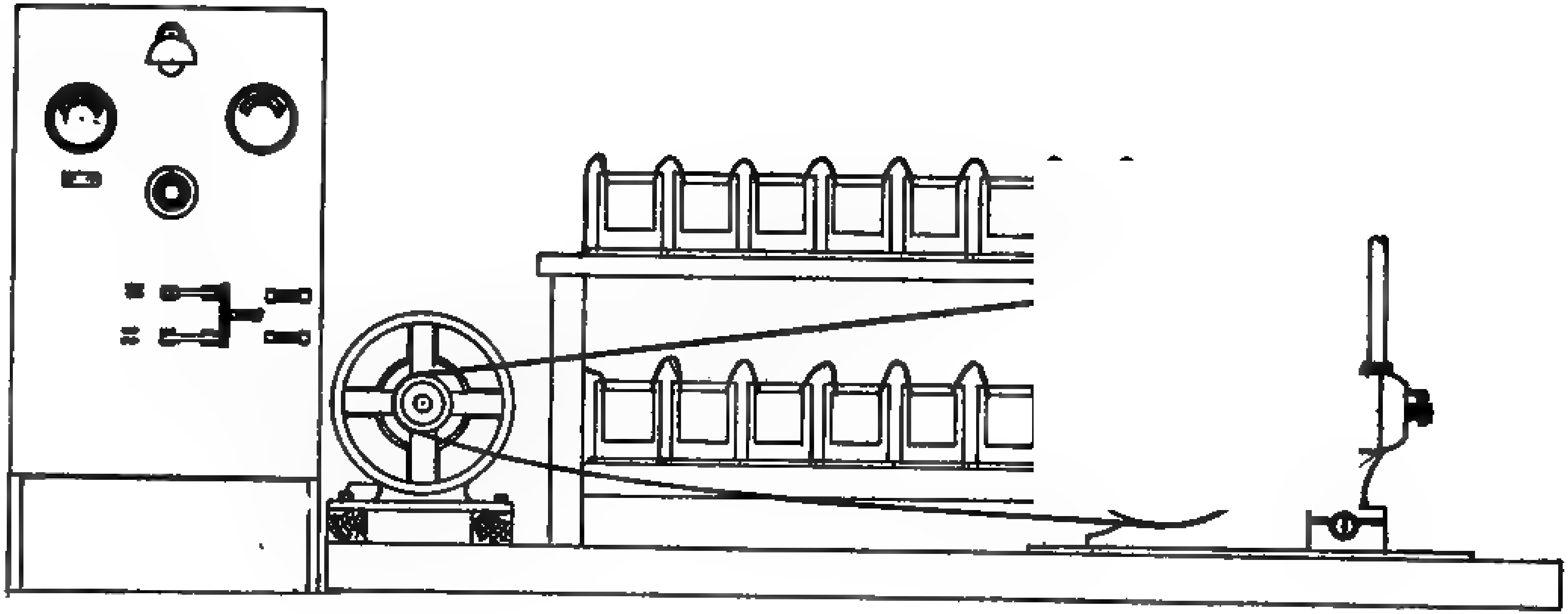


Fig. 8.

The cost of installation has been omitted as the plant can be set up by the farmer himself in his spare time. An expert wireman can make the electrical connections for the plant in a day. The cost of wiring a six room house, including two lamp fixtures in two rooms and pendent lamps in the other rooms and on the porches, with flush switches on the wall to control the lamps will be about $50.00. The total cost of the installation is then $400.00.

If fully charged at the start the battery will supply lamps with energy as shown in Table 2.

TABLE 2.

Hours	Number of 16 C. P tungsten lamps	Number of 16 C. P. carbon filament lamps
3	15	5
4	12	4
6	9	3
8	8	3
10	7	2

A six room house could probably be lighted two or three days without recharging the battery. It takes eight hours to charge the battery, so that the engine need be operated only about 3 hours per day or eight hours every two or three days.

The annual cost of operation is as follows:

Interest, $400 at 6%	$24.00
Depreciation of engine and battery, $175 at 10%	17.50
Depreciation of other equipment, $225 at 5%	11.25
Lamp renewals	5.00
Gasoline, oil and supplies	20.00
Repairs and taxes, $400 at 2%	8.00
	$85.75

The cost of light per month is $7.15. In the above calculations we have assumed that no motors are to be used. It is perhaps unfair to charge all the investment costs of the engine to the lighting installation as the engine can and probably will be used for other purposes. Again the fire insurance on the buildings that have electric lights would probably be reduced so that the cost of light may be reduced on this account. However we do not believe that it is possible to light a country residence with an isolated electric plant for less than $5.00 per month when all the cost factors are considered.

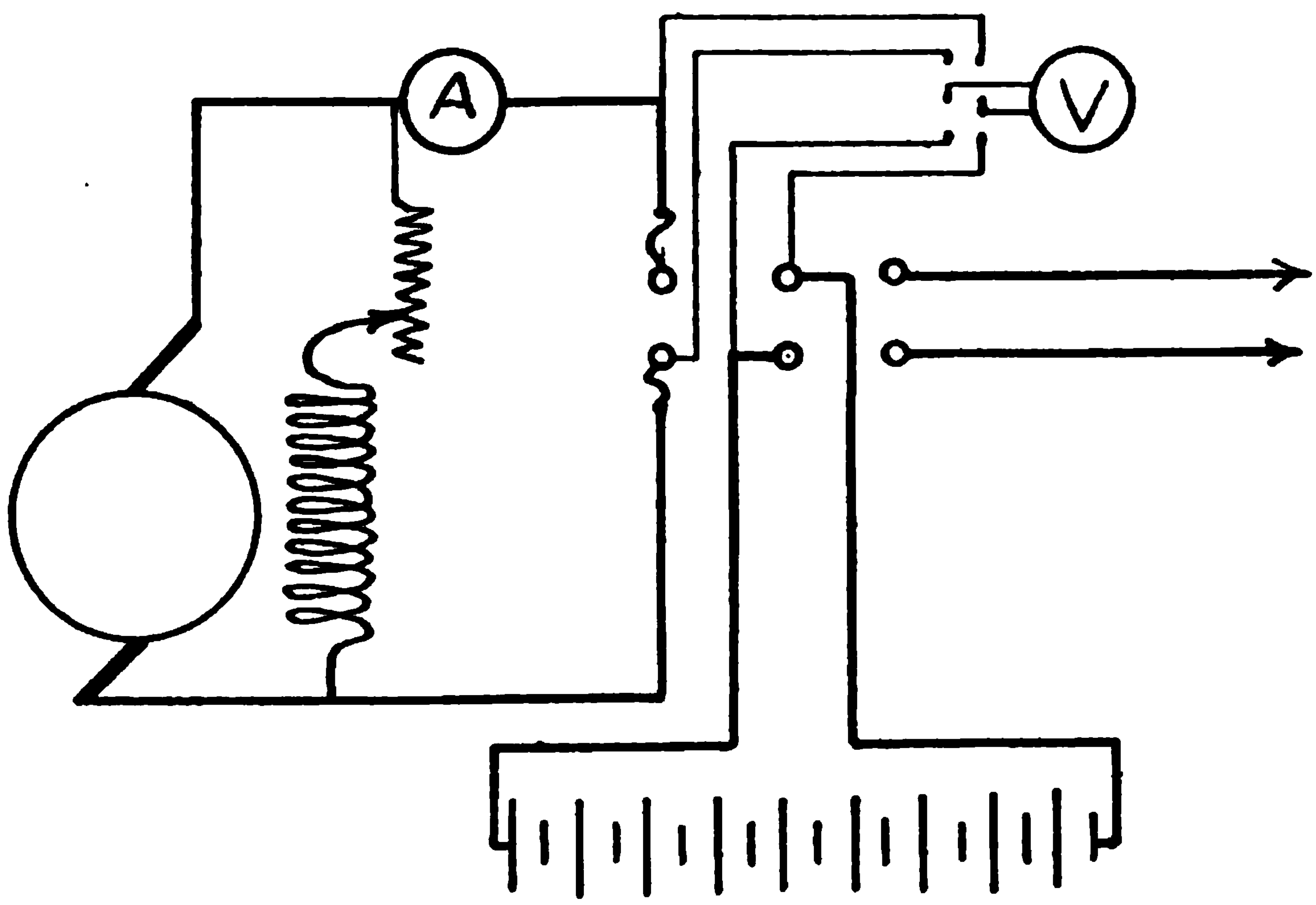


Fig. 4.

A somewhat larger plant with more refinements than the one just considered and some added advantages will now be considered. This plant can be started from the switchboard, without the necessity of "cranking" the engine, by using the battery to operate the dynamo as a motor. The motor turns the engine and with the ignition switch closed an explosion results after a few revolutions. By the use of counter E. M. F. cells, it is possible to charge the battery while power is being used for lighting or to use the combined capacity of the battery and generator to operate a large motor for a short time. Thus it is possible to obtain full 24 hour service and also to carry large loads for a short time if it is desired. The initial cost of the installation is about as follows:

Switchboard	$120.00
Engine, 2 horsepower	150.00
Generator, 1 kilowatt	100.00
Battery	290.00
Belt, foundation, piping, etc.	25.00
House and barn wiring	75.00
	$760.00

The battery has the following capacity:

Hours	No. of 16 C. P. Tungsten lamps	No. of 16 C. P. carbon filament lamps	Watts
3	45	16	900
4	37	13	750
6	27	10	550
8	22	8	450
10	19	7	380

If the combined capacity of the battery and generator is used, the output is increased 1000 watts, which is enough to supply 50 16-C. P. tungsten lamps or 18 16-C. P. carbon filament lamps. A two horsepower motor can be used three or four hours before the battery is exhausted, after which all the power will have to come from the generator, and the plant can then supply only about a 1-horsepower motor. It is very evident from this that there is no economy in using the isolated plant for motor service. Driving the generator requires a two-horsepower engine which can just as well be of the portable type so that it can be used for other farm work when not required to charge the battery. This makes the full two-horsepower of the engine available for power instead of only one-half of this amount which the electric motor will deliver.

The annual expenses of the plant just described are:

Interest, $760.00 at 6%............................	$ 45.60
Depreciation of engine and battery, $440 at 10%...	44.00
Depreciation of other equipment, $320 at 5%........	16.00
Taxes and repairs, $760 at 2%......................	13.20
Lamp renewals	10.00
Gasoline, oil and supplies.........................	40.00
	$168.80

Summary—Isolated Plants.—The cost of supplying electric power by an isolated plant is low when only the actual costs of production, or manufacturing costs, are considered, and the interest on the investment, and depreciation of the machines are neglected. This is what most advertisements and catalogues do whenever they show a low cost for lighting country homes by this method.

As a summary we may state that the isolated electric plant is satisfactory from the standpoint of convenience, reliability, safety, low operating expenses and general utility. However the first cost

is high and this makes the yearly charge, or fixed cost, higher than that of either gasoline or acetylene lighting outfits. Electric lighting has many advantages over gas lighting, which makes it unfair to figure the relative merits of different systems from economic standpoints only. The added advantages of electric lights somewhat compensate for the higher first cost of the plant, so that the service and merits of all systems should be carefully weighted and balanced against their respective costs.

In all cases where the best system is wanted regardless of cost, the isolated electric light plant is most satisfactory. In many other cases we believe that it will be chosen, not because of its cheapness, but because of its many advantages.

RURAL DISTRIBUTION OF ELECTRIC POWER.

An earlier part of this bulletin shows the advantages and economy of using electric power in rural districts and also that its use has increased in the past few years; a large increase in the next decade is predicted. Inasmuch as isolated plants are unsatisfactory for power purposes and usually are not economical for lighting purposes, means of obtaining electrical energy on farms must often be obtained elsewhere.

The author of this bulletin believes that the solution of the problem of obtaining electric power on the farm lies in the purchase of energy from a central electric station. The only disadvantage of this is the fact that a long transmission line is needed to serve only a few customers. The farmers can either co-operate to build this line past their several homes and connect with a nearby city plant, or preferably they can influence the central station to build the line by a promise of sufficient business to make the enterprise profitable for the station. In the first case, the energy would be purchased and measured at the city limits. The price per unit of energy would be very low as the character of the load makes it desirable for the central station to serve this class of customers. The farmers corporation would pay for line losses, transformer losses, line repairs and all superintendence. They would also pay fixed charges on the investment such as taxes, interest and depreciation, so that the cost of power at their several homes would be considerably higher than at the city plant. If the central station were to build the line, they would have to receive all the above items as well as a fair profit on the investment from the farmers in their monthly bills, but as the larger company could probably install and maintain the system more economically, the cost of power to the farmer would be about the same as if they owned the distribution system. As the yearly cost of energy is about the same in

either case, it is of course preferable for the farmers to induce the central station to build the line so that the initial investment will be a minimum.

Rural Distribution from Viewpoint of Power Plants.—From the viewpoint of the central station we may say that rural lines have proven profitable to many central stations in the Mississippi valley. The load is well distributed throughout the day, motors being used during "off peak" periods. The lighting peak, which is usually small, does not exactly coincide with the city lighting peak due to the differences in the habits of the two classes of customers. Because of the fact that rural lines help to increase the load factor, the business is very desirable, while the cost of developing the power will in general be little more than operating expenses as no additional plant equipment is needed. Some companies require the customer to pay part of the cost of the pole line, but this joint ownership of property by customers and utility corporations may lead to future difficulties. The company may require an advance payment equal to all or part of the cost of line construction, this money to be applied on future power bills. The company may require that each farmer build his own branch line from the main distribution line, and furnish his own transformer and meter, or pay rental on the same to the central station. In general, the more the customer furnishes, the lower the unit cost of power must be, while if the equipment paid for by the farmer is excessively large few customers will be secured. If the power plant furnishes everything, the price of power per unit may be so high that there will be difficulty in securing many customers. These two factors must be balanced to suit local conditions.

The first year's business may not, and probably will not, show any profit, but after the advantages are once seen by the farmers a fair income is the natural result. This has been the experience of several small central stations in neighboring states, and also of the large western plants which supply power for irrigation. The entire matter hinges on whether enough power can be sold to take care of the high investment charges. Each power plant operator must judge for himself what his market conditions will be. Later in this paper there are given some examples of typical lines under different load conditions, with costs completely analyzed. From these, some idea of the feasibility of rural distribution can be obtained after the market conditions have been studied.

General Scheme.—Regardless of whether the distribution system is paid for by the farmers, by the station or by both, the general design and construction will be the same. If the line passes through

the city, it is necessary to transmit the power to the outskirts of the city at the regular city distributing voltage, which in most cases for small cities is 2200 volts. A special line may be built from the plant or the city mains may be used if they have sufficient capacity to give good regulation on the long rural lines. It is best to use a separate line from the power house, as complete control of the long system is then afforded at the station switchboard, and any trouble on the rural line, which is very susceptible to interference, will not affect the city customers. The disadvantage of this plan lies in its increased cost.

Voltage.—In the case of many systems, distribution may be effected at 2200 volts while in some cases where the load is large, or the distance great, 6600 volts must be used. In the latter case, an outdoor pole type transformer with a simple outdoor oil switch, and high tension fuses must be installed at the city limits, unless permission can be secured to run a 6600 volt line through the city streets, in which case the transformer and protective apparatus may be installed in the plant. It is not desirable to use a higher voltage than 6600 for direct distribution, as transformers are not made in the very small capacities for higher voltages. As each customer must have a separate transformer at his home, many small transformers will be required. If it becomes advisable to use a higher voltage than 6600, it is preferable to make two transformations. Thus the main transmission line voltage will perhaps be 16500. Branch circuits will be extended to several customers at 2200 volts and again transformed to 110 or 220 volts at the farmers' homes. This makes a complicated system, but one that has proven satisfactory to a few central stations which transmit power from their main plant to small towns near by and supply power to farmers located along their transmission lines.

Three Phase vs. Single Phase Systems.—The fact that rural distribution of electrical power can be effected economically and profitably is generally conceded, provided farmers can be induced to make use of motors for the many operations in which power can be advantageously applied, and if no unusual features are necessary in the distribution system.

From the farmer's standpoint, a three phase system is preferable. A single phase motor and one transformer costs more than a three phase motor and a bank of transformers for three phase use. The three phase motor is best adapted to farm use because it is simpler, more rugged and has electrical and mechanical characteristics which make it more suitable to the farmer's particular use.

As the central station's profit depends to a great extent upon the amount of the motor load, and as a large motor load can be best secured by extending satisfactory service at a reasonable cost, it seems highly advisable to gain the good will of the customers by giving them the advantages of the use of three phase motors. Since it is always advisable, and in many cases essential, to secure a large motor load, it follows naturally that a three phase transmission line should be used under all except extreme conditions.

If a small motor load, and a large lighting load can be secured at the time of installation, it may be wise to erect a single phase system at first which will later be changed to three phase when there is a possibility of increasing the motor load. The saving of copper and insulators made by using the one phase instead of the three phase system will be about $60 per mile for very lightly loaded lines, where sufficiently good regulation can be secured with a single phase line using No. 8 or No. 10 copper wire and 2200 volts. In case a large wire or a higher voltage must be used to secure good regulation with a single phase system, it is economical to change to a three phase system. If the cost of power lost is a deciding factor in selecting the size of conductor, then three phases will be most economical, since to transmit the same amount of power with the same line loss the three phase system requires only three-fourths as much copper as the single phase system.

It is thus seen that a three phase system is the most economical to use in all except very lightly loaded lines. As it is very doubtful if lightly loaded rural lines could be profitably installed, it appears that in all cases where a rural line is feasible, three phase systems should be used.

Besides the three wire three phase system, there is another which might be profitably used, namely the three phase four wire system. The primaries of the transformers are delta connected to the 2200 volts 3 phase circuit, while the secondaries are arranged in star and the fourth wire connected to the neutral, which is usually grounded. This gives with three 2200 volt primary 2200 volt secondary transformers a voltage of 2200 volts from any wire to the neutral, or to ground, with 3800 volts between any two outside wires. The copper economy and regulation are almost as good as in a 3800 volt 3 wire 3 phase system, while the voltage strains to ground which have to be met are only those of a 2200 volt circuit. Since the size of the conductors vary inversely as the square of the voltage a large saving in line material can sometimes be made by using this system.

Design of Distribution System.—In the design of a rural distribution system, the engineer is confronted by several economic

problems which are different from those encountered in either a city distribution system or in a long distance power transmission line. The load will in general be small and widely distributed and will be subject to large fluctuations. The lighting load will, of course, obey the same general laws that apply in any distribution system, but motors will be used at infrequent intervals, and consequently high peaks may occur at unexpected times, while the average load will be low. These peaks will not affect the station as they will generally occur at times when the plant is lightly loaded. Also they will be far below the capacity of the plant, but they may tax the ability of the distribution system to deliver power with good regulation.

As the average load is small and as absolute continuity of service is not essential a construction of a light character is permitted and even necessary if the central station is to realize a profit. The fixed charges on the cost of the conductors will usually exceed the cost of the line loss. Therefore the smallest conductors that will give good regulation should be used. To keep down investment charges, the first pole line should be constructed as cheaply as is compatible with safety. An interruption in the service of a few hours, while being undesirable is permissible, as farmers do not need absolute continuity of service so much as service itself. The line need not be made more expensive to secure uninterrupted service although in some instances repairs could be greatly reduced by a little better initial installation.

In the long run a cheaply constructed line would probably be more expensive than one of better construction on account of its high maintenance costs. In constructing a line into new territory there is some uncertainty as to the revenue which may be derived, and a possibility that the project may be abandoned entirely after a few years trial. A line of low first cost will minimize the financial loss in such an event.

Once the business is established, however, the line must be regarded as a permanent installation and all permanent installations should be designed to secure the lowest total annual cost, including depreciation and maintenance charges as well as the interest on the initial investment.

Poles.—In general the pole line should resemble that now used for rural telephone lines. A twenty-five or thirty foot wooden pole should be used as it is sufficiently long and much cheaper than longer ones. If twenty-five foot poles set five feet in the ground are used the lowest part of the span will be at least 15 feet from the ground. This is sufficient for any place except road or railroad

crossings. At road crossings thirty or thirty-five foot poles should be used and at railroad crossings the poles should be larger and set close to the right of way on each side. Many different kinds of wood are used for poles, such as cedar, pine, chestnut, cypress, redwood, fir, spruce and juniper, but the engineer can easily be guided in his choice by considering the cost. The cheapest pole should be selected for the initial installation, but for later lines, after the system has become a profitable enterprise a pole should be selected for which maintenance and depreciation charges are a minimum. This selection is made by dividing the first cost of the pole by the number of years of life and adding the yearly cost of repair and attendance, such as painting or resetting.

The life of poles, according to various authorities, is given in Table 4.

TABLE 4.

Material	Life in years
Cedar	12 to 20
Pine	6 to 10
Redwood	15 to 20
Fir	15 to 20
Chestnut	12 to 15
Cypress	9 to 10
Juniper	8½
Steel	25
Structural Iron	25
Concrete	Indefinite except for mechanical injury

It has been proven beyond any possibility of doubt that a pole which has been treated with the proper preservative has a much longer life than an untreated pole of the same material. The usual preservative is creosote. This material is introduced into the pores of the wood by several different methods, which may be divided into three general classes, namely: vacuum process, open tank process and painting. The vacuum process requires expensive apparatus and is utilized only by companies using a large number of poles. Poles treated by this method however can be purchased from some companies. The other two methods are directly appliable for use by small companies and farmers. In the open tank process, the butts of the poles are placed in heated preserving materials contained in an open tank of proper size. The cost of treating poles in this manner is low and very good results are obtained. In many cases

painting the poles with the proper preservative will greatly lengthen their useful life. It is claimed by some engineers that these two cheaper processes are just as good if not better than the more expensive vacuum process. We are not in a position either to prove or to disprove this statement. Line poles usually decay first at about the level of the ground and this part of the pole at least should be painted since the cost is low and much useful life is added to the pole. Whether the pole should be treated more than this

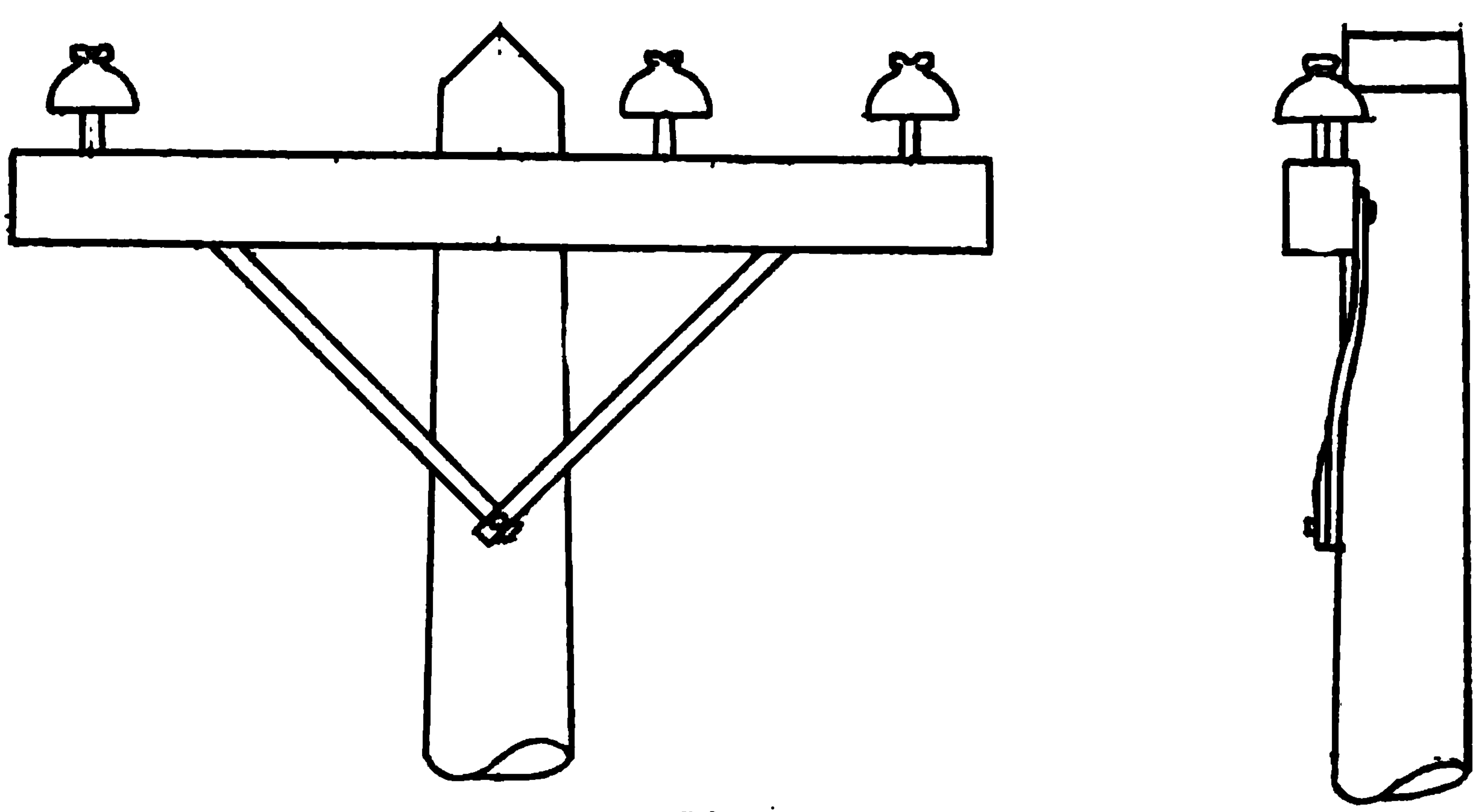


Fig. 5.

depends entirely upon the cost and the added life. If the added life will more than pay for the treating, then the poles should be treated if possible.

Cross Arms.—Cross arms as well as poles are made from several different woods and the same general rules apply in their selection. They need not be treated, but should be rounded on top and well painted. Their life is usually less than that of the pole because they are sawed from large logs and so the grain is exposed to the elements. To secure the cross arm to the pole, a gain is cut in the pole into which the arm is fitted and a bolt is passed through both; or lag screws may be used passing through the arm into the pole. Sometimes iron braces are added to make the cross arm more secure in its position. Cross arms, braces and pins for insulators should be placed in position on the poles before erection. Figure 5 shows pole top construction.

Cross arms on two adjacent poles face in opposite directions.

Insulators.—Insulators are usually made of glass or porcelain, pin type insulators always being used for low voltages. Glass insu-

lators are very much used on low voltage distribution systems for both the secondary and the high tension lines while porcelain is used on all very high tension systems. Glass is cheaper but it is not as strong, or as good an insulator as porcelain. For 2200 volt systems glass insulators will probably be used because of their cheapness. For 6600 or 13200 volts glass or porcelain may be used while for voltages above this porcelain should be used. The difference in cost of line using different kinds of insulators will not be great since all low voltage insulators are comparatively cheap.

The insulators are secured to the cross arms or poles by wooden pins, steel pins, or wooden brackets. On rural lines wooden pins are best for use on cross arms.

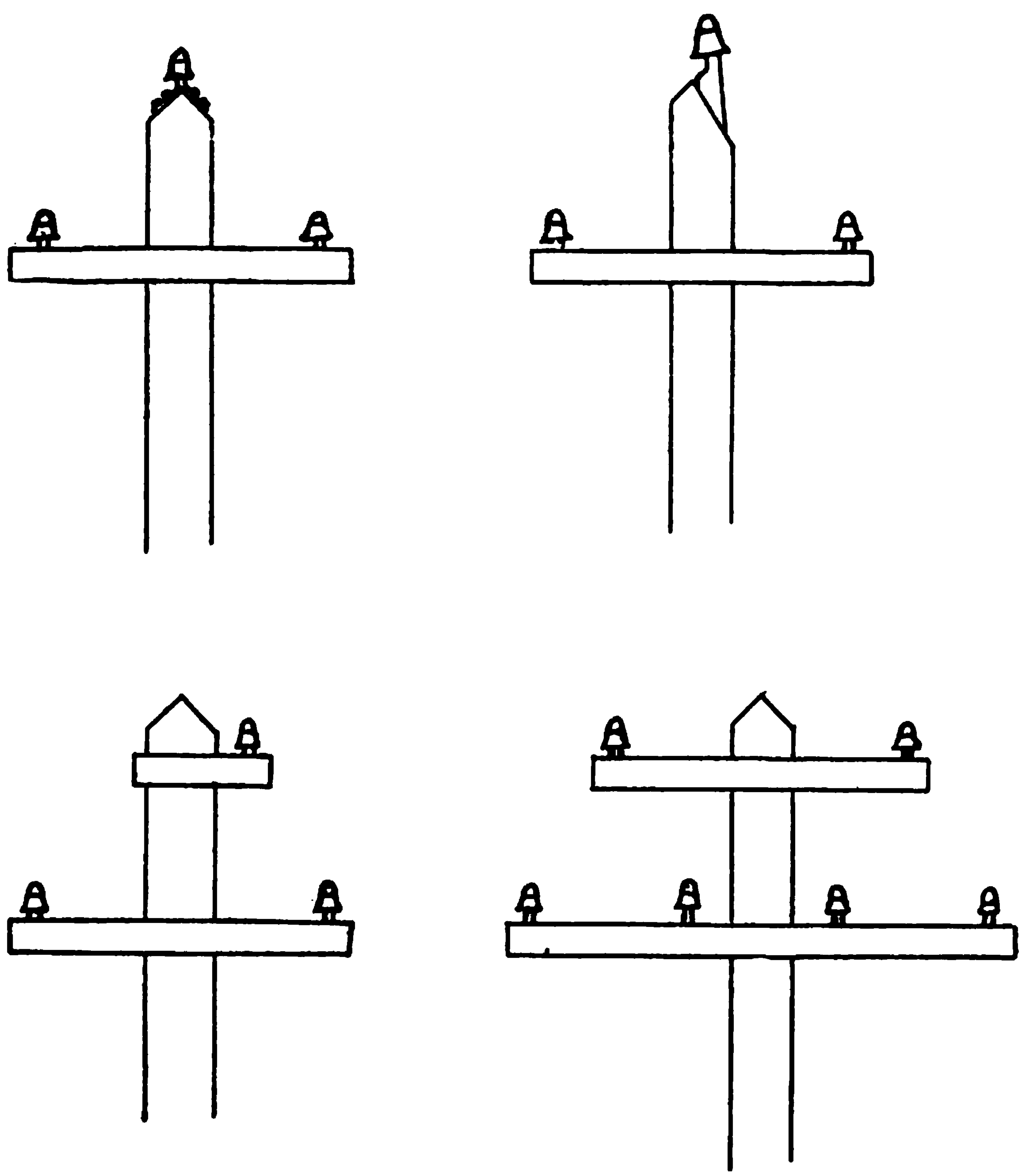


Fig .6.

Arrangement of Conductors.—A single phase system requires but two wires and two insulators per pole which should be placed on the ends of a short cross arm placed near the top of the pole. This arrangement is the same as is shown in figure 5 except that the center insulator is to be omitted.

A three phase system requires three wires and three insulators per pole which may be placed in the form of an equilated triangle or all in one plane as shown in figure 5. The triangular construction is best, several forms of which are shown in figure 6.

If the three conductors are secured in one plane on a long cross arm they should be transposed every mile to keep the voltage the same on all three phases.

If there are telephone lines near the distribution system, the wires should be transposed frequently even with the equilateral triangular arrangement.

Line Conductor Calculations.—The selection of the proper size of conductor, and the proper voltage is a complex and rather difficult problem. There are three factors which must be considered; mechanical strength, voltage regulation and total annual cost. The regulation must be sufficiently good for the service. The cost of supplying all distribution losses, plus the fixed charges on the installation should be a minimum. For some new installations the line losses may be greatly increased to reduce the first cost thus making the sum more than the minimum. But either mechanical strength or voltage regulation is usually the controlling factor in determining the size of conductors, the line losses being a secondary consideration since the cost of supplying them is usually far less than the fixed charges on the equipment.

Assuming sufficiently close regulation for the service expected, we shall proceed on the basis of securing the cheapest installation. The line which is at first selected may be somewhat modified later to reduce distribution losses. There are several factors which affect the regulation of an alternating current distribution system such as size of conductors, kind of system (one phase or three phase), voltage, spacing of conductors, load and power factor. The costs which are varied by changing either the size of conductor or the voltage are: the cost of conductors, insulators, protective devices, switches and transformers. A change in the voltage or size of conductor also affects the line copper loss, the transformer copper loss and the transformer iron loss.

Of these several factors, some can be eliminated by inspection. The load and power factor are fixed by the customers. The use of single phase or three phase system is determined by several factors

as discussed on page 21; a three phase system should be used in most cases. The spacing of conductors is determined by the liability of accidental contact. We thus have left only the size of conductors and voltage to be considered in the design of the system.

To secure a given regulation, we may use a small wire and high voltage or a large wire and low voltage. In the former case, the line copper cost is small and the cost of transformers, insulators, switches and protective devices is high. The transformer iron loss is also high. In the latter case these relations are reversed. It is evident that there is a certain size wire and voltage which will give a minimum cost for all the elements concerned.

The most satisfactory method of determining the proper size of the conductors and the proper voltage is by trial. First assume that No. 8 or No. 10 wire is to be used, depending upon the mechanical strength necessary. Then find the standard voltage which will give sufficiently good regulation and compute the costs of all variable elements. Next consider the next lower standard voltage and select the proper conductor for the required regulation, again computing the cost of all variable elements. The distribution losses and the cost of supplying them are also calculated for both installations. After all these are tabulated the proper selection may be made.

The following formulae have been found to be valuable. For a certain conductor (No. 8 or No. 10) the voltage which gives the required regulation is

$$E = a\,b\,c\,\sqrt{D\,P}$$

Where E = Voltage between conductors

D = Distance in thousand feet to the center of distribution

P = Total K. V. A. which may be connected to line at one time

a, b and c are constants

"a" takes into account the kind of system. For

1 phase, $a = \sqrt{2} = 1.414$

3 phase, $a = 1$

2 phase, 3 wire, $a = 1$ (common conductor must be larger than outside conductors)

2 phase, 4 wire, $a = 1$

3 phase, 4 wire, $a = 1$ (where E = voltage between two outside wires)

$$b = \left(\frac{\text{Reg}}{1000\ R}\right)^{1/2}$$

Where R = resistance of 1000 ft. of conductor as given in the table below.

Reg = required regulation expressed as a decimal (thus: 3% regulation = .03)

b for different size conductors and different regulations is plotted in the curves on page 30.

c is a constant which takes into account the reactance of the line and the power factor of the load. In other words it is a constant to change the regulation which would be obtained in a direct current system to the regulation which is obtained with an alternating current system. For 100% power factor c is always unity and for most rural lines at any expected power factor is sufficiently accurate if assumed equal to unity. The exact value of c is found from the curve on page 32 as explained later.

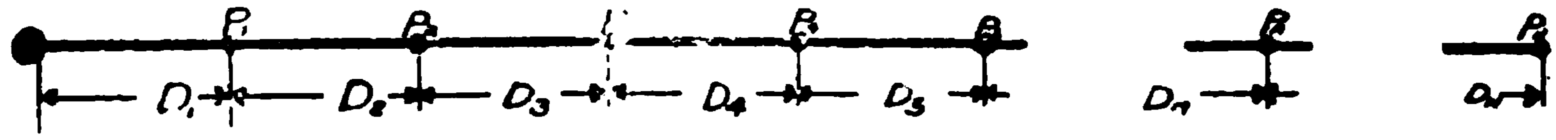
D = distance in 1000 of feet to the center of distribution of the system

$$D = [(P_1+P_2+P_3+P_4+\ldots+P_n)D_1 + (P_2+P_3+P_4+\ldots+P_n)D_2 + (P_3+P_4+\ldots P_n)D_3 + (P_4+\ldots+P_n)D_4+\ldots+(P_m+\ldots+P_n)D_m + P_nD_n] \div [P_1+P_2+P_3+P_4+\ldots+P_n]$$

Where P_1, P_2, P_3, P_4, ... P_m, ... P_n are the connected loads of individual customers in KVA, and D_1, D_2, D_3, D_4, ... D_m, ... D_n, are the distances between them in thousands of feet.

The proper size of conductors for a certain voltage and a required regulation, may be determined by the use of the following formula:

$$R = \frac{1}{a^2 c^2} \cdot \frac{E^2 \text{Reg}}{1000\,DP}$$



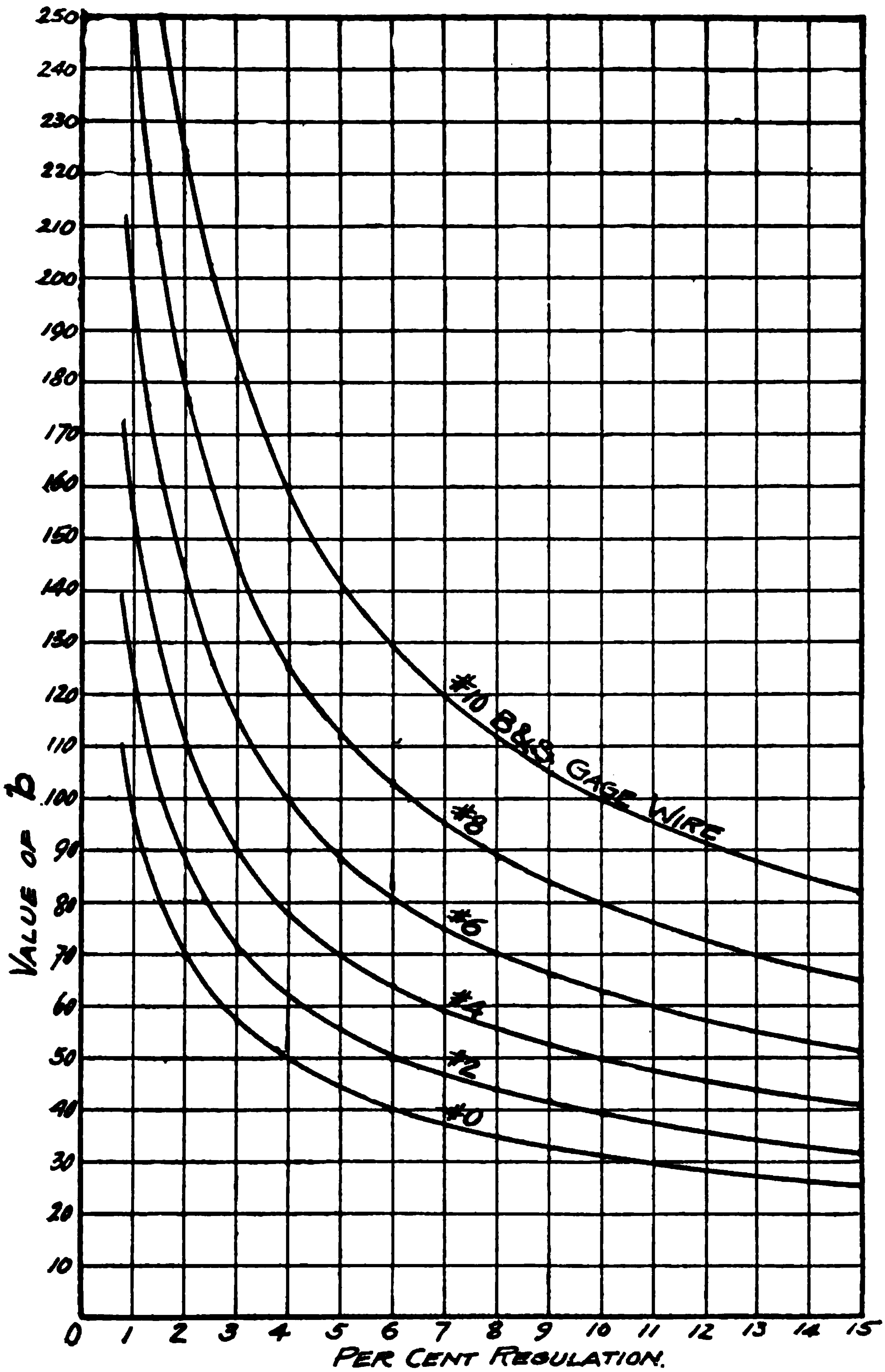
Supply end of line

Fig. 7.

The value of R per 1000 feet of commercial copper wire is shown below:

Size wire B & S Gauge	10	8	6	4	2	0	00	000	0000
R	.9972	.6271	.3944	.248	.156	.09811	.0778	.0617	.04893

To find c from the curve on page 32 proceed as follows: Draw a vertical line through the points which correspond to the spacing of the wires, and at the point where this line intercepts the curve corresponding to the size of the wire used, draw a horizontal line until it intercepts the curve corresponding to the power factor of the system. From this intersection draw a vertical line to the top of the figure and read the value of "c" from the scale. This gives



250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Value of b
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Per Cent Regulation.
#10 B&S Gage Wire
#8
#6
#4
#2
#0

Fig. 8.

the proper value of c to use. As an example: find the value of c for a system using No. 6 wire spaced three feet apart and having 80% power factor. The vertical line through the three foot point is the heavy line about the center of the page. This intersects the No. 6 curve at a ratio factor of .37. Through this point draw a horizontal line which intersects the 80% power factor curve at a value of c equal to 1.03 which is the proper value for these conditions.

A Special Distribution System.—As an example of the design of a distribution system for rural communities let the following problem be assumed: A city plant has a three phase 2200 volt generating equipment of ample capacity to supply the load for a line as given in the following table. The manufacturing cost of power is one cent per kilowatt hour. At the switchboard the selling price of power for off peak service is one and one-half cents per kilowatt hour and the selling price of power for peak service is six cents per kilowatt hour. The customers and the individual connected loads are as follows:

Customer	Distance from city in 1000 feet.	Connected Light load in K. W.	Connected Motor load in H. P.	Required Transformers		Remarks
				No.	K.V.A. rating each.	
A	1	1	0	1	1	
B	2	½	0	1	½	
C	3	½	3	2	2	Motor used 20 hrs. per day 3 months per year to irrigate truck farm
D	5	1	0	1	1	
E	5	1	5	2	3	General service motor
F	5	½	0	1	½	
G	6	½	0	1	½	
H	8	1	10	2	7½	General service motor
I	10	½	0	1	½	
J	11	1	3	2	2	General service motor
K	11	½	0	1	½	
L	13	1	2	2	2	Motor used 10 hrs. per day throughout yr. for pumping water
M	14	½	0	1	½	
N	16	½	10	2	7½	General service motor
		10	33			

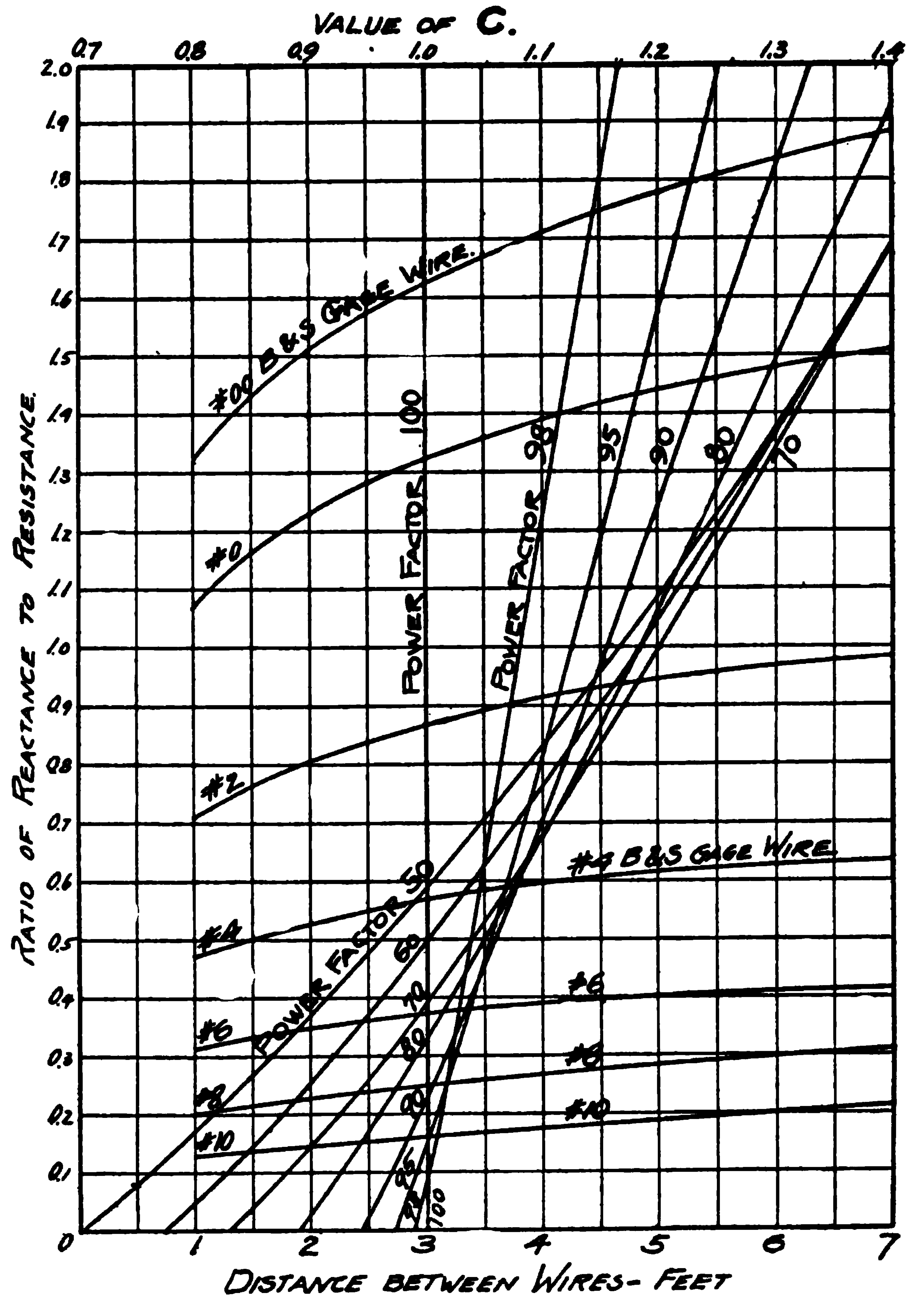

VALUE OF C.
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RATIO OF REACTANCE TO RESISTANCE
#00 B&S GAGE WIRE.
#0
#2
#4
#4 B&S GAGE WIRE
#6
#6
#8
#8
#10
#10
POWER FACTOR 100
POWER FACTOR 98
95
90
80
70
POWER FACTOR 50
60
70
80
90
95
98
100
1
2
3
4
5
6
7
DISTANCE BETWEEN WIRES - FEET

Fig. 9.

D for motor service is calculated as follows:

$P_1 = 3,$	$D_1 = 3$	$(P_1 + \ldots. + P_6)D_1 = 33 \times 3 =$	99
$P_2 = 5,$	$D_2 = 2$	$(P_2 + \ldots. + P_6)D_2 = 30 \times 2 =$	60
$P_3 = 10,$	$D_3 = 3$	$(P_3 + \ldots. + P_6)D_3 = 25 \times 3 =$	75
$P_4 = 3,$	$D_4 = 3$	$(P_4 + \ldots. + P_6)D_4 = 15 \times 3 =$	45
$P_5 = 2,$	$D_5 = 2$	$(P_5 + \ldots. + P_6)D_5 = 12 \times 2 =$	24
$P_6 = 10,$	$D_6 = 3$	$(P_6 + \ldots. + P_6)D_6 = 10 \times 3 =$	30
			333

$$D = \frac{333}{33} = 10.09$$

D for lighting service is found as follows:

$P_1 = 1,$	$D_1 = 1$	$(P_1 + \ldots. + P_{11})\ D_1 = 10 \times 1 =$	10
$P_2 = \frac{1}{2},$	$D_2 = 1$	$(P_2 + \ldots. + P_{11})\ D_2 = 9 \times 1 =$	9
$P_3 = \frac{1}{2},$	$D_3 = 1$	$(P_3 + \ldots. + P_{11})\ D_3 = 8\frac{1}{2} \times 1 =$	8.5
$P_4 = 2\frac{1}{2},$	$D_4 = 2$	$(P_4 + \ldots. + P_{11})\ D_4 = 8 \times 2 =$	16.
$P_5 = \frac{1}{2},$	$D_5 = 1$	$(P_5 + \ldots. + P_{11})\ D_5 = 5\frac{1}{2} \times 1 =$	5.5
$P_6 = 1,$	$D_6 = 2$	$(P_6 + \ldots. + P_{11})\ D_6 = 5 \times 2 =$	10.
$P_7 = \frac{1}{2},$	$D_7 = 2$	$(P_7 + \ldots. + P_{11})\ D_7 = 4 \times 2 =$	8.
$P_8 = 1\frac{1}{2},$	$D_8 = 1$	$(P_8 + \ldots. + P_{11})\ D_8 = 3\frac{1}{2} \times 1 =$	3.5
$P_9 = 1,$	$D_9 = 2$	$(P_9 + \ldots. + P_{11})\ D_9 = 2 \times 2 =$	4.
$P_{10} = \frac{1}{2},$	$D_{10} = 1$	$(P_{10} + \ldots. + P_{11})\ D_{10} = 1 \times 1 =$	1.
$P_{11} = \frac{1}{2},$	$D_{11} = 2$	$(P_{11})\ D_{11} = \frac{1}{2} \times 2 =$	1.
			76.5

$$D = \frac{76.5}{10} = 7.65$$

From an examination of the load conditions it is evident that the motor load which may occur at one time is 5 H. P. plus a part of the 28 H. P. in general motors. Let it be assumed that one-half of the general service motors may at some time be connected.

$$\text{Then } P = 5 + \frac{28}{2} = 19 \text{ H. P.}$$

1 H. P. in an induction motor requires about 1 KVA.

Then $P = 19\text{KVA}$

For induction motor service 10% regulation is sufficiently good. The values found above may now be substituted in equation (1).

$$E = abc\sqrt{DP}$$

$a = 1$ for 3 phase system

$b = 79$ for No. 8 wire and 10% Reg. from the curve on page 30.

c = .98 for a system using No. 8 wire spaced 28″ and with 80% power factor, from curve, page 32. This gives

$$E = 1 \times 79 \times .98 \sqrt{10.09 \times 19} = 1074 \text{ volts.}$$

As 2200 volts is the next higher standard voltage, and is also the voltage of the city system, No. 8 wire and 2200 volts may be considered as being suitable for the motor service.

For lighting service the voltage is found as follows:

a = 1

b = 145 for No. 8 wire and 3% regulation from the curve on page 30.

c = 1.01 for 98% power factor and No. 8 wire spaced 28″.

$$E = 1 \times 145 \times 1.01 \sqrt{7.65 \times 5} = 906 \text{ volts.}$$

and

It has been assumed in the above that one-half of the total connected lighting load will be supplied at one time. Therefore if the line is constructed of No. 8 wire spaced 28″ and the power is distributed at 2200 volts, the proper regulation will be given. This regulation has been assumed to be 10% for induction motor service, and 3% for lighting service. The motor and lighting load will not occur at the same time so that we are safe in designing the system for the one load which presents the severest conditions. There is no need to consider any other voltage than 2200 since the cost can not be lessened by changing any of the factors. However, it may be interesting to consider the financial condiitons and the economic feasibility of a distribution system such as this one which is fairly typical of a small line after a few years operation.

Assuming that the customer purchases his own transformer and meter and also builds his own branch line from the main distribution system, the initial cost of this system is composed of the folfolwing items:

2390 lbs. No. 8 bare hard copper wire at $20 per 100 lbs......	$478.00
120 25-ft. poles, 40 per mile, at $3.50 each..................	420.00
120 3-ft. cross arms, at $0.25 each..........................	30.00
360 2200 volt insulators, at $0.04 each......................	14.40
120 sets pole hardware, bolts, braces, pins, etc.............	18.00
Labor, setting poles, placing cross arms and insulators......	240.00
Labor, stringing wires	75.00
Incidentals	75.00
Switches, fuses and lightning arresters....................	149.60
3 mile line complete costs..........................	$1500.00

This distribution system can be cheapened by using ¼″ galvan-

ized steel strand in place of No. 8 copper wire the regulation still being better than the standards which have been set, but the future capacity will not be quite so large. The system as now designed will take care of several times the present assumed load and with ¼″ galvanized steel strand about 1.3 times the present assumed load. Under these new conditions the cost will be

4800 ft. ¼″ galvanized steel strand, at $0.75 per 100 ft.	$320.00
90 30-ft. poles, 30 per mile, at $4.50 each	405.00
90 3-ft. cross arms, at $0.25 each	22.50
270 insulators, at $0.04 each	10.80
90 sets pole hardware	13.50
Labor, setting poles, placing arms and insulators	180.00
Labor, stringing wires	100.00
Incidentals	75.00
Switches, fuses and lightning arresters,	149.60
3 miles line complete costs	$1276.40

This saving is made because of the lower cost of the steel wire and because ¼″ steel strand has several times the mechanical strength of No. 8 copper wire so that we can space the poles farther apart.

The yearly cost to the central electric company will be as follows:

Fixed charges composed of 6% interest, 7% depreciation and 3% taxes and repairs, total 16% of $1276.40	$204.23
Iron loss in transformers, 4664 Kw hrs. at $0.01	46.64
Copper loss in line and of transformers, 300 Kw hrs	3.00
Supervision, attendance and clerical	100.00
Total yearly cost	$353.87

The total power sold is found as follows:

If one-third of the connected lights are used three hours per day, then 3650 Kw hrs. will be sold for lighting purposes. The use of general purpose motors is assumed as 5 hours per day for one-seventh of the motors, or each motor will be used 5 hours per week. The motor load is:

Irrigation	3 x 20 x 90	5400 hp. hrs.
Pumping	2 x 10 x 365	7300 hp. hrs.
General	— x 5 x 365 7	7300 hp. hrs.
Total		20000 hp. hrs.

And 20000 horsepower hours delivered at the motor shaft requires about 18000 kilowatt hours motor input. From the sale of this amount the central station must receive the cost of power at the switchboard, the cost of distributing it, and a profit on the cost of the distribution system. The distribution cost is $353.87, a 10% profit is $127.64, and $481.51, or 2.22 cents per Kw. hr., must be added to the price of power at the switchboard. This makes the cost of electric power to the farmer for motor use, 1.5 + 2.2 = 3.7 cts. per Kw. hr. and for lighting purposes 6 + 2.2 = 8.2 cts. per Kw. hr.

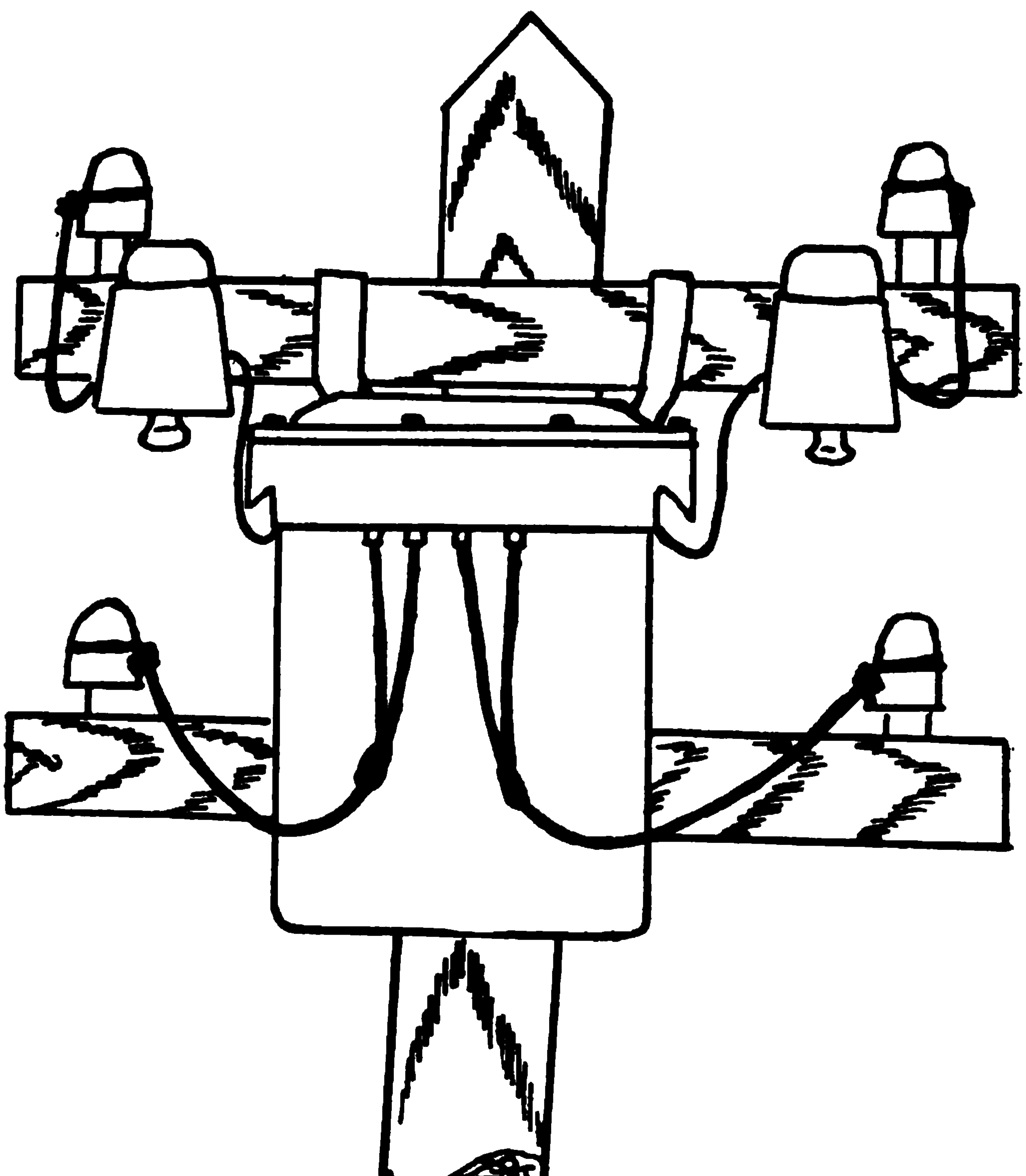


Fig. 10.—Mounting of a Transformer

Cost of Electric Service to Farmer.—It may be interesting to see what the farmer actually pays for the use of electric power. First, consider the case of a farmer who uses electricity for lighting a small residence, taking Mr. B. of the preceding problem as a fair

example. He has an installation of twenty 25-watt tungsten lamps to light his six room residence. His investment is as follows for two 2-lamp fixtures and six pendant lamps, first class installation:

Wiring	$50.00
Meter	10.00
Transformer, ½ KVA	20.00
Branch line from his home to line, ¼ mile	80.00
Total	$160.00

His yearly expenses are as follows:

Fixed charges, 14% of $160.00	$22.40
Lamp renewals	3.00
Current, 180 Kw. hrs. at $0.082	14.76
Total	$40.16

His actual yearly expense will be $40.16, but he will pay the central electric company an average of only $1.20 per month.

As a typical example of the cost of motor service, consider the case of Mr. E. who has twenty-five 40-watt tungsten lamps in his residence, barn and other buildings and uses a five horsepower motor for general service. The total power used is:

Lighting, 1/3 x 3 '365 = 365 Kw. hrs. at $0.082	$29.95
Motor, 4.4 x 5 x 52 = 1144 Kw. hrs. at $0.037	42.30
Total yer year	$72.25
per month	6.00

His investment is as follows:

House and barn wiring	$75.00
Meter	10.00
Two 3 KVA transformers at $35.00	70.00
Branch line, home to line, ¼ mile	80.00
Motor, 5 H. P. 3 phase, 1800 RPM	80.00
Total	$315.00

The total cost is as follows:

Fixed charges, $315.00 at 14%	$41.10
Power	72.25
Oil, waste and sundries	5.00
Lamp renewals	5.00
Total	$126.35

The cost for the lighting system is..........................$50.75
The cost for motor service is 75.60

Compare the above motor cost with the cost of doing the same work with a gasoline engine.

A 5 H. P. engine complete costs............................	$250.00
The fixed charges are, interest 6%, depreciation 10%, taxes and repairs 4%, a total of 20% on $250.00................	50.00
Gasoline, 1/6 gallon per horsepower hour with 10% for leakage and waste, amounts to 238 gal., at $0.18 per gal......	42.80
Oil, waste, batteries and sundries............................	15.00

The total for a gasoline engine is..................$107.80
The total for electric motor is...................... 75.60

The electric motor is thus much cheaper as well as safer and far more convenient and reliable.

Typical Large Rural Distribution System.—Let it be assumed that a central electric company, having a three phase 2200 volt plant, wishes to supply power for a rural line as outlined in Table 17. The company is to supply transformers and branch circuits, but each customer must purchase his own meter. The manufacturing cost of power is one cent per kilowatt hour and the profitable selling price at the switchboard is one and one-half cents per kilowatt hour for "off peak" and six cents per kilowatt hour for peak load power.

Customer	Distance in 1000 of ft.	Lighting load in K.W.	Motor load in H.P.	Remarks
A	1	1	3	Gen'l purpose motor 5 hrs. per wk.
B	1	1	5	Truck farm, used 20 hrs. per day in summer.
C	2	½	3	Gen'l purpose motor 5 hrs. per wk.
D	3	1	Two 5 H.P.	Truck farm used 20 hrs. per day in summer.
E	4	1	0	
F	6	½	Two 5 H.P.	Truck farm used 20 hrs. per day.
G	8	1	3	Gen'l purpose motor 5 hrs. per wk.
H	9	1	10	Pumping 10 hrs. per day through the year.
I	10	1	10	3 H.P. motor pumping 5 hrs.per day
			3	
J	13	½	0	
K	14	1	0	
L	16	1	5	Gen'l purpose motor 5 hrs. per wk.
M	17	2	0	
			5	5 H.P. motor general purpose 5 hrs per week
N	18	½	3	3 H.P. motor pumping 5 hrs. per dy
O	21	1	10	Gen'l purpose motor 3 hrs. per wk.
P	23	1	3	Gen'l purpose motor 5 hrs. per wk.
Q	25	1	4	Gen'l purpose motor 5 hrs. per wk.
			10	10 H.P. motor general purpose 4 hour per week.
R	26	½	3	3 H.P. motor pumping 5 hrs. per dy
S	28	1	5	Gen'l purpose motor 5 hrs. per wk.
T	29	½	0	
U	33	1	Two 10 H.P.	Power 5 hrs. per week.
V	34	1	5	General purpose motor.
W	35	½	10	Power.
X	37	15	10	Power.
Y	40	1	5	Gen'l purpose motor 5 hrs. per wk.

From an inspection of the table it is evident that the line must be designed to take care of the motor load as it presents decidedly the worst conditions. We shall therefore proceed to find **D** for the motor load.

$P_1 = 8$,	$D_1 = 1$	$(P_1 \ldots P_{19})D_1$	$= 157 \times 1 = 157$
$P_2 = 3$,	$D_2 = 1$	$(P_2 \ldots P_{19})D_2$	$= 149 \times 1 = 149$
$P_3 = 7$,	$D_3 = 1$	$(P_3 \ldots P_{19})D_3$	$= 146 \times 1 = 146$
$P_4 = 10$,	$D_4 = 3$	$(P_4 \ldots P_{19})D_4$	$= 139 \times 3 = 417$
$P_5 = 3$,	$D_5 = 2$	$(P_5 \ldots P_{19})D_5$	$= 139 \times 2 = 258$
$P_6 = 10$,	$D_6 = 1$	$(P_6 \ldots P_{19})D_6$	$= 126 \times 1 = 126$
$P_7 = 13$,	$D_7 = 1$	$(P_7 \ldots P_{19})D_7$	$= 116 \times 1 = 116$
$P_8 = 5$,	$D_8 = 6$	$(P_8 \ldots P_{19})D_8$	$= 103 \times 6 = 618$
$P_9 = 8$,	$D_9 = 2$	$(P_9 \ldots P_{19})D_9$	$= 98 \times 2 = 196$
$P_{10} = 10$,	$D_{10} = 3$	$(P_{10} \ldots P_{19})D_{10}$	$= 90 \times 3 = 270$
$P_{11} = 3$,	$D_{11} = 2$	$(P_{11} \ldots P_{19})D_{11}$	$= 80 \times 2 = 160$
$P_{12} = 4$,	$D_{12} = 2$	$(P_{12} \ldots P_{19})D_{12}$	$= 77 \times 2 = 154$
$P_{13} = 13$,	$D_{13} = 1$	$(P_{13} \ldots P_{19})D_{13}$	$= 73 \times 1 = 73$
$P_{14} = 5$,	$D_{14} = 2$	$(P_{14} \ldots P_{19})D_{14}$	$= 60 \times 2 = 120$
$P_{15} = 20$,	$D_{15} = 5$	$(P_{15} \ldots P_{19})D_{15}$	$= 55 \times 5 = 275$
$P_{16} = 5$,	$D_{16} = 1$	$(P_{16} \ldots P_{19})D_{16}$	$= 35 \times 1 = 35$
$P_{17} = 10$,	$D_{17} = 1$	$(P_{17} \ldots P_{19})D_{17}$	$= 30 \times 1 = 30$
$P_{18} = 15$,	$D_{18} = 2$	$(P_{18} \ldots P_{19})D_{18}$	$= 20 \times 2 = 40$
$P_{19} = 5$,	$D_{19} = 3$	$(P_{19})D_{19}$	$= 5 \times 3 = 15$
			3355

$$D = \frac{3355}{157} = 21.35$$

In estimating the value of **P** the conditions governing the use of the motors must be carefully considered. Let it be assumed that all truck farm motors are connected, that 75% of the pumping motors are connected at one time and that one-third of the general purpose motors may be connected. Near the end of the line are three power installations for rock quarries and rock crushers, and all of these may be connected at one time so that the maximum possible load is:

Truck farms		22.00	H. P.
Pumping	19 x .75 =	14.25	H. P.
General	71 x 1/3 =	23.65	H. P.
Power		45.00	H. P.
Total	**P** in H. P. =	104.9	H. P.

As one H. P. in motor capacity requires about 1 K. V. A., **P** in K. V. A. = 104.9

It is now necessary to find the voltage which is necessary to transmit this power at 80% power factor over a three phase system using No. 8 copper wire spaced 28 inches apart.

$P = 104.9$
$D = 21.35$
$a = 1$
$b = 79$ for 10% regulation curve page 30.
$c = .98$ curve page 32.
$E = abc\sqrt{DP}$
$E = 1 \times 79 \times .98\sqrt{21.35 \times 104.9} = 3670$ volts

As 6600 volts is the next higher standard voltage it must be selected if it is desired to use a straight three phase system. A four wire, three phase, star connected system with 2300 volts between any wire and the neutral or 3980 volts between outside wires may also be used. This necessitates three transformers at each motor. The use of this latter system provides for 18% future growth while a 6600 volt three phase system allows a future load of 3.2 times the present load. As this load is hardly to be expected, 5/16″ steel strand wire may be substituted and still allow for considerable future business. A three phase, 2200 volt system requires No. 3 B. & S. copper wire and allows 15% future business. This gives three possible designs to choose from: 6600 volts three phase 5/16″ steel strand; 3980 volts three phase, four wire, with No. 8 copper wire conductors and ¼″ steel strand for the neutral; and 2200 volts three phase with No. 3 copper wire. To make a selection between these three the cost of each should be considered.

Items	Cost of a 7½ mile line		
	6600 volts 3 phase 5/16" steel strand	3980 volts No. 8 copper wire ¼" steel strand neutral	2200 volts 3 phase No. 3 copper wire
400 30' poles spaced 100 ft., at $4.50......		$1800.00	
300 35' poles spaced 40 per mile, at $7...	$2100.00		$2100.00
400 cross arms and set of pole hdw'r @45c		180.00	
300 cross arms and set of pole hdw'r @45c	135.00		135.00
1600 2200-volt insulators, at 4c..........		64.00	
1200 2200-volt insulators, at 4c..........			48.00
1200 6600-volt insulators, at 5c..........	60.00		
Labor setting poles	650.00	800.00	650.00
Labor stringing wires	225.00	225.00	225.00
40000' ¼" steel strand..................		300.00	
120000' 5/16" steel strand...............	1200.00		
5390 lbs. No. 8 bare copper wire.........		1079.00	
10900 lbs. No. 3 bare copper wire........			3635.00
Switches, lightning arresters and fuses..	600.00		
Total 7½ mile line....................	$4970.00	$5948.00	$7193.00
Total per mile	$663.00	$792.00	$959.00
Total Costs			
Step up transformers, 3 phase...........	$ 600	$ 560	
Distributing transformers, all single phase	3400	2300	$2300
Branch lines, averaging ⅛ mile..........	1800	2250	1800
Main line	4970	5948	7193
Total	$10770	$11058	$11293

There is very little difference in the cost of the three different systems for this installation so other than financial factors must be considered in making the selection. The third system is probably the best because it can be changed to a 3 phase 4 wire system having three times its present capacity if the future business becomes large or if it is desirable to extend the line. Futhermore, 2200 volts is the most common distribution voltage.

The total amount of power sold annually is as follows:

Lighting	6155	Kw. hrs.
Truck farms	34600	
Pumping	44500	
Power	59000	
General	16200	
	160455	Kw. hrs.

Fig. 11.—Two Transformers on a Three-Phase System.

The amount to be realized over and above selling price of power at switchboard is:

Fixed charges	$1810.00
Transformer iron loss	152.00
Copper loss	21.00
Profit 10%	1130.00
Supervision, clerical and attendance	800.00
Total	$3963.00

Additional cost per KW hr........................2.47 cents

The proper selling price of power at farmer's residence is thus:

$1.5 + 2.47 = 3.97$ cts. per KW. hr. for day load and

$6 + 2.47 = 8.47$ cts. per KW hr. for lighting service.

This selling price is higher for the heavily loaded line because the central electric station owns not only the transmission line but also the branch circuits and transformers.

Economics of Rural Distribution.—The only argument which will influence central electric stations to extend their service to rural districts must be based on income and profit. Examples of two distribution circuits have been given which show the selling price of electrical energy must be in order to make a profit on the entire investment. The first example is a short line with a medium load, built to keep down first costs. The second is a large heavily loaded rural line constructed in a first class manner, and designed for most economic operation. Neither line shows the conditions encountered on very lightly loaded rural lines.

A rural distribution system must earn a certain profit over and above all expenses including fixed charges, and this profit must be as large as can be earned by investing the same capital in other enterprises having the same degree of uncertainty. The expenses are: interest on the line investment, taxes, repairs and depreciation of the system, clerical and supervisional charges and cost of supplying all distribution losses (of which transformer iron losses are the largest) as well as the profitable selling price of electrical power at the switchboard. This price of power at the switchboard is less than the city selling price, as city distribution expenses do not have to be met. The actual profitable selling price of power at the switchboard varies through very wide limits at the different times of the day due to the varying load on the plant. At "off peak" times during the day when farm motors are mostly used, the equitable price of power may be less than one-fourth the price at the evening lighting peak time, so that a low rate for motor service is always justified if there is a high peak caused by some other load. It must not be thought that because this energy is sold at a low price there

is no profit. Considering the profit on the investment required to serve the customers, motor service at a low unit price is just as profitable if not more so that the high priced lighting load.

With the exception of copper loss, which is very small, and clerical work, all the cost of distributing power over a given line is constant regardless of the amount of power which the customers use. Therefore the distributing charge per kilowatt hour varies inversely as the number of kilowatt hours sold. A line which has a heavy load usually has a better type of construction, so that this relation does not hold strictly true for two different lines.

An analysis of the cost of rural distribution shows that the following is approximately true: Copper loss is generally a negligable factor and will seldom exceed one per cent of the power sold. Transformer iron losses are usually high unless high tension disconnecting switches are provided to disconnect the transformers where they are not in use and this may be economical in some instances. For 2200 volt distribution, transformer iron losses will amount to about one per cent of the connected transformer capacity continued 24 hours per day, which amounts to 88 kilowatt hours per year per K V A in connected transformer capacity. For higher voltages, the iron losses are higher than this. Fixed charges on the investment are usually high considering the amount of power sold. A fair estimate of them is as follows:

Item	Per cent
Interest, (at current rate)	4-6
Depreciation of pole line (depends on type)	5-15
Depreciation of conductors	3-8
Taxes (at current rate)	
Repairs	1-5

A central station should consider nothing less than 10% profit on the investment as the business is slightly hazardous and 15% would probably be a better figure to use in preliminary computations for new lines.

To find the economical selling price of power at the farmer's homes the following formula will apply.

$$P = \frac{FC + pC + L}{\text{KW hrs. per year per mile}} + S$$

Where **P** is the selling price per kw. hr.,

F is the fixed charges in percent of total investment, assumed as 16% in our previous calculations,

p is the percent profit,

L is the cost per mile of supplying line losses.

C is the average cost per mile of all the apparatus and lines owned by the electric power company,

S is the profitable selling price of power at the switchboard varying for different service plus a small amount for clerical and supervision work.

The total amount which must be added per kilowatt hour to the economic price of power at the switch board is

1000 KW hrs. per year per mile	15.0 cents
2000 KW hrs. per year per mile	8.5 cents
4000 KW hrs. per year per mile	5.0 cents
10000 KW hrs. per year per mile	2.5 cents
20000 KW hrs. per year per mile	1.5 cents
40000 KW hrs. per year per mile	1.0 cents

This table is based on a line costing about $650 per mile, and a connected load about ten times the average load. The values given vary but little with different lengths of transmission. It is probable that the cost of lines for lightly loaded systems can be reduced below $650 per mile, so that the selling price of power for these lines can be reduced.

Distribution from High Tension Transmission Lines.—The trouble and expense of many small substations make it unwise to serve small customers from high voltage transmission lines, unless enough customers can be supplied from one transformer station to warrant the construction of a substation of the best type, with constant attendance to secure reliability of serve to the customers, and with the best protective apparatus to protect the main transmission line from disturbances originating on the customer's circuits. The income from isolated customers is seldom large enough to be profitable even after the element of risk of interruption of the main transmission service by local disturbances on the branch circuits has been subtracted. To secure full protection to the substation apparatus, a reliable and positive lightning arrester must be placed at each station; to protect the transmission system, reliable circuit breakers must be installed to interrupt the service in case of trouble. Since both of these protective devices must be designed for the transmission voltage, they are necessarily expensive. Small high voltage transformers are also costly. If uninterrupted service is to be extended to the customers, there must be constant attendance. To secure all these qualities the apparatus should preferably be enclosed in a building. All of these factors make it uneconomical and unprofitable to serve small isolated customers.

If, however, a number of customers who do not require absolute continuity of service can be connected to one substation, and

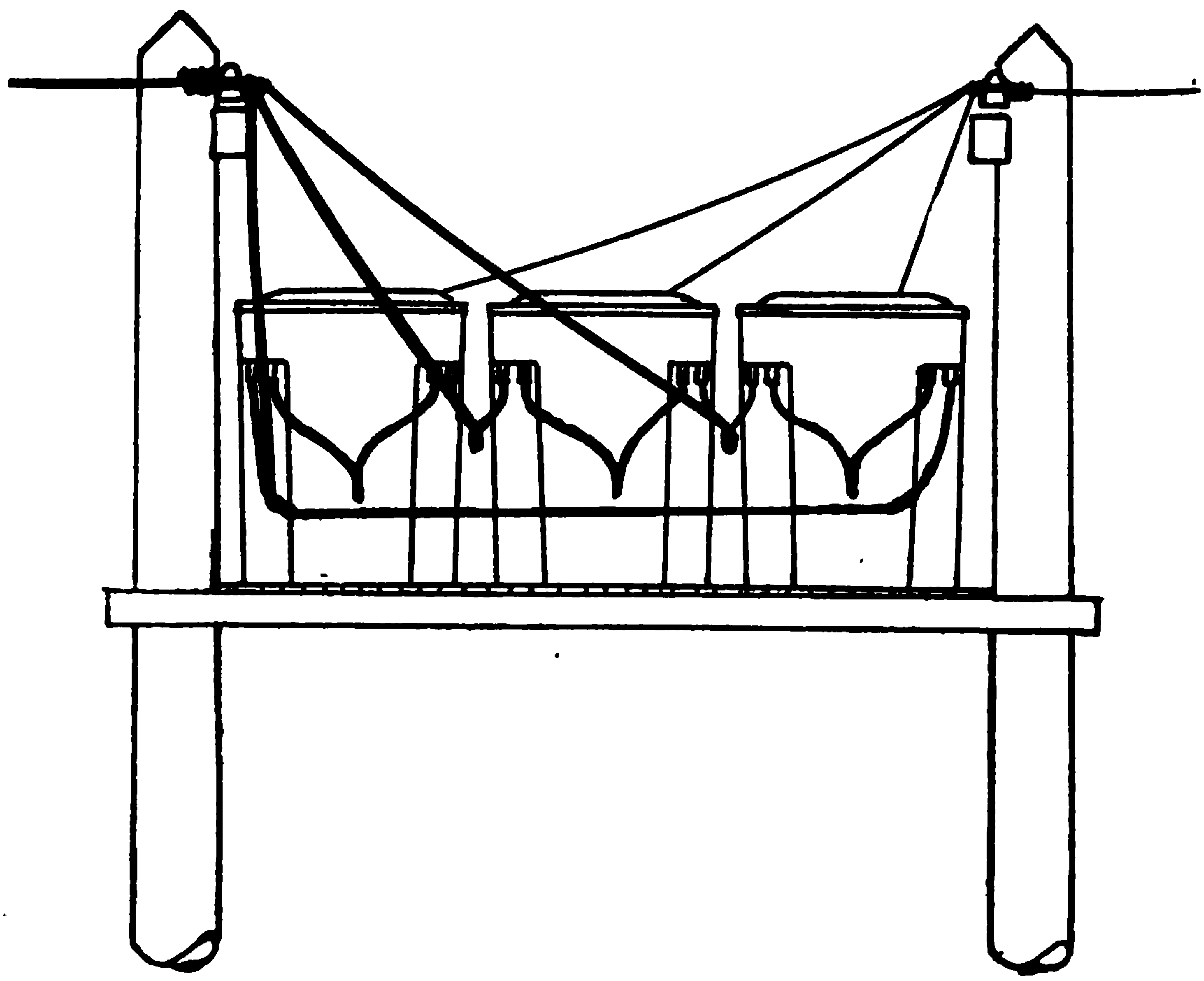


Fig. 12.—Bank of Three Transformers on a Three Phase System.

the company is willing to assume the risk of interruption of the main service, there is no reason why these customers should not be provided with electrical power. This is the case with farmers. A rural distribution system such as is described in the second problem discussed in the preceding pages could be economically and profitably served with an outdoor transformer station of 100 KVA capacity from a 33,000 or possibly a 44,000 volt transmission line. Constant attendance can be dispensed with since farmers do not require continuity of service as much as the service itself. Several companies now design outdoor transformers in small capacities for high voltages, using cheaper types of apparatus than are used for large transformer stations.

Notwithstanding the fact that the apparatus available for this service leaves something to be desired, many power companies use, and several manufacurers make sets for the protection of small outdoor transformer stations. These sets are composed of a disconnecting switch, a high tension fuse of a special design, a choke coil, and a horn gap lightning arrester. In case of a short circuit on the branch the fuse is blown. A lightning disturbance entering from

the line is reflected by the choke coil to the horn gap where it discharges, the arc being broken by the natural operation of the horn gap. In case the arc is not extinguished at once, the high tension fuse which is in series with the arrester as well as the other apparatus, is blown. Thus in case of a short circuit or in some cases of lightning discharge, the circuit is opened by the fuses until they are replaced by an attendant. Whenever any work is to be done on the station, the station can be made dead by opening the disconnecting switches after the low tension switches have been opened. While this system does not secure continuity of service to the customers, and does not fully protect against transient disturbances, yet it is the best cheap installation that can be made under present conditions. A substation which would serve the customers on the farmers' line described under problem 2 would cost about $1800.

The annual expenses are:

Amount to be realized from distribution line	$3963.00
Fixed charges, 16% of $1800	288.00
Profit, 10% on $1800	180.00
Transformer iron loss	100.00
Supervision and attendance	200.00
Total	$4731.00

The amount to be added to the selling price of power to defray distribution costs is 2.94 cents per kilowatt hour, which is a very reasonable figure. Therefore, if a sufficiently good load can be connected to one substation, and if the customers do not demand absolute continuity of service, as is the case with farmers, and if the power company is willing to assume the risk of interruption of the main transmission service and to keep the transformer station in satisfactory operation, a fair revenue at a good profit is derived from serving farmers, even from a 33000 volt transmission line.

Special Central Electric Plants.—In several European countries, for example Germany, Italy and Norway, there are now in operation many small central electric plants situated in the centers of well developed farming countries. These plants have distribution systems extending to the homes of the farmers within a reasonable radius. Some of the larger plants are steam driven, many of the small ones are gasoline or oil engines, while a few utilize water power. Many of them are direct current plants using a storage battery to secure continuous service to the farmers with intermittent operation of the generator and prime mover.

While we do not know all the conditions surrounding the establishment of these plants, it appears that they are less economical

than distribution from city plants or high voltage transmission lines. The satisfactory method of securing electric power on farms in America does not lie in the direction of small isolated plants. If, however, it is not possible to secure power from a large central plant, it is better and more economical for two or more farmers living near each other to use one isolated plant such as described earlier in this bulletin rather than for each farmer to have his own separate plant. The isolated plant described under problem 2 on page 17 would satisfactorily supply two small residences with light at a cost about the same as that given by supplying one residence. The cost to each farmer would be little more than one-half of the cost given previously. But this is a refinement of the isolated plant rather than a central station of the kind used in Europe.

A central plant for the use of farmers would need to be a small installation of the same type as the large city plants. There is no need of multiplying the number of small plants in a country when in general one large station can supply energy more economically than several small ones. The large plants are already installed and they will need little extra equipment to serve a large number of farmers by means of a few distribution lines. They should be used wherever possible.

CONCLUSION.

It is undisputed that farmers will find as much satisfaction in the use of electric light as any other customers. Electric motors can be profitably used almost daily in many farm processes because of their convenience, ease of operation, flexibility, lack of noise and dirt, long life, small repair charges and general overall economy. It is usually uneconomical for farmers to own and operate isolated plants since the fixed charges are high, and such plants are not well adapted to supplying motors with power. It therefore seems preferable to distribute power from a central electric plant by means of a high voltage distribution system. This is economical to the farmer and profitable to the central station if a good motor load can be secured. The best system will usually be found to be a three phase system, either three wire or four wire, with a voltage such that standard 2200 volt or 6600 volt distributing transformers can be used. The entire line should be designed for as low a first cost as is consistent with durability and general engineering practice. In the selection of the system for a particular line, the cost of all applicable systems should be considered. It is sometimes profitable for power companies to install small outdoor transformer stations to supply rural lines.

Small central stations supplying power to farmers only, and with no other market, are not likely to prove successful financially. Distribution from a city central electric station or a long distance high voltage transmission line is always to be recommended where feasible as being the most satisfactory to all concerned in obtaining electricity for lighting and power in rural districts.

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COMPARATIVE TESTS OF CYLINDER OILS

BY

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UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
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COMPARATIVE TESTS OF CYLINDER OILS.

INTRODUCTION.

The cylinder oil tests described in the following pages are to be regarded as a continuation of Vol. 2, No. 2 of the Engineering Experiment Station Series: "Friction and Lubrication Testing Apparatus" by Mr. A. E. Flowers, formerly Assistant Professor of Electrical Engineering, University of Missouri. This bulletin was a report on the oil testing apparatus devised by him, and which has been used to test and compare the lubricating values of the samples of cylinder oils reported in the present bulletin.

It is generally agreed among operating engineers, that the present specifications based on the chemical and physical constants of an oil (the specific gravity, flash and fire tests, viscosity, acidity, per cent animal and vegetable fat, etc.), do not give sufficient information as to their value as a friction and wear reducing agent. Even these chemical and physical constants are very often not supplied to the purchaser, with the result that the operating engineer finds himself in a difficult position when he has to choose between a certain number of oils of different costs, different compositions and of different and also unknown lubricating values.

It was this difficulty experienced in the selection of a proper cylinder oil to be used at the Light and Heat Station of the University of Missouri, that has led the Engineering Experiment Station to develop an apparatus for the testing of the lubricating value of cylinder oils under conditions identical to every-day practice.

Nine samples of cylinder oils, designated by the first nine letters of our alphabet, were tested; the results of these tests are given in the following pages.

PHYSICAL PROPERTIES.

Color and Consistency. The color and consistency of the oils tested are given below:

Oil	Color	Consistency
A	Dark brown	Thick
B	Dark green	Thick
C	Dark	Thick
D	Brown	Thick
E	Dark brown	Thick

F	Brown	Thick
G	Reddish brown	Limpid, flows easily
H	Black	Thick
I	Reddish	Clear, flows easily

Specific Gravity. The specific gravity or the weight per unit volume of the oils at different temperatures was determined by using a direct reading hydrometer, and their comparative values are shown in Figure 1, where the specific gravity is plotted as a function of the temperature.

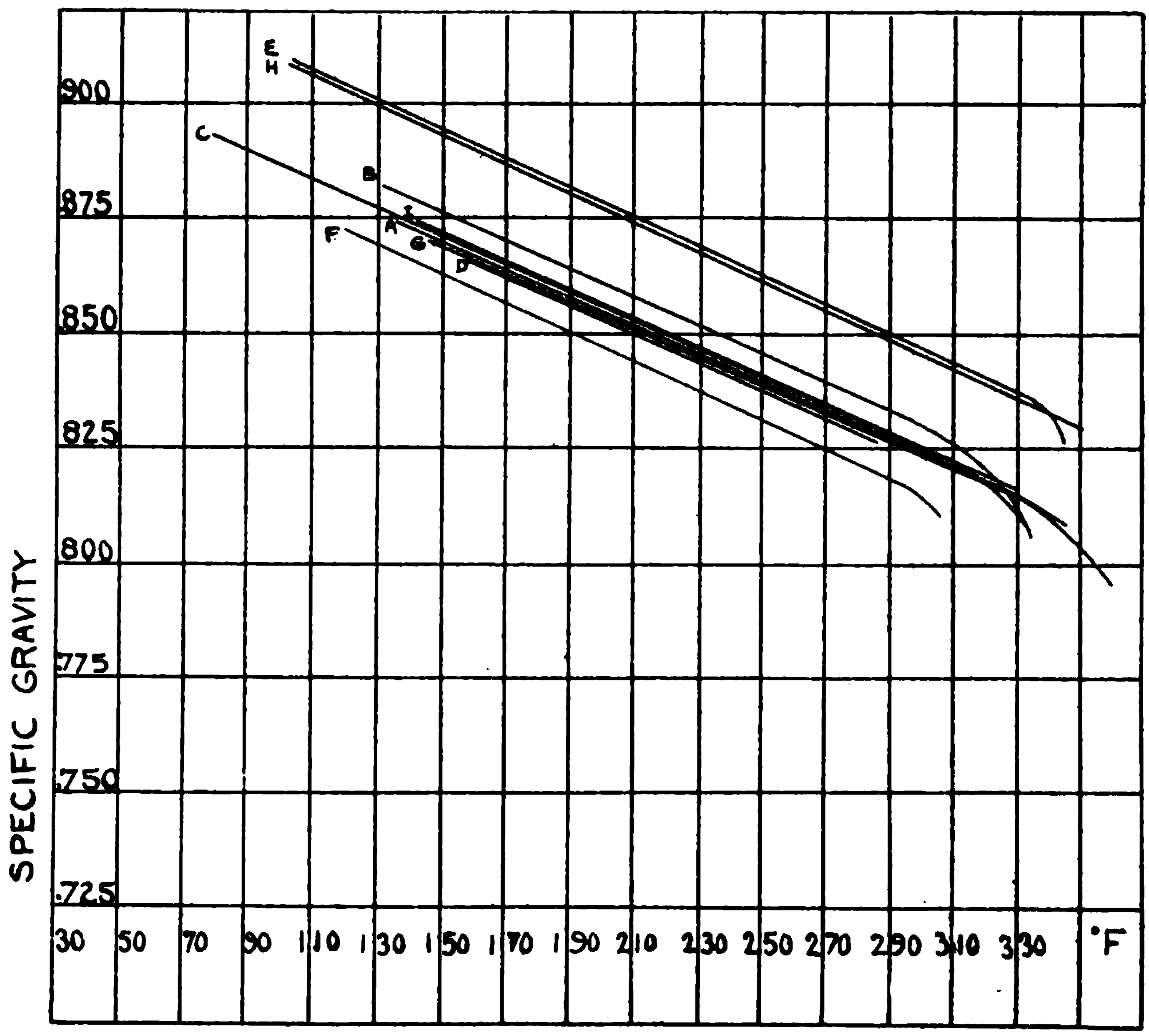

Fig. 1

From these curves we can readily see that as to their comparative heaviness at the temperature of boiling water (212°F) the oils tested rank as follows:

TABLE 1.

Oil	Sp. Gr.
E	.875
H	.873
B	.857
A	.855
I	.855
C	.855
G	.851
D	.849
F	.844

It is to be noted the oils A, C and I, though entirely different as to color and consistency have the same specific gravity throughout the range of temperatures under which they have been tested.

Flash and Fire Tests. The open flash point is the temperature at which the oil flashes under atmospheric pressure when a flame is brought near its surface. This was determined in the usual manner by nearly filling a tin cup with a sample of oil and heating it gradually over a sand bath and passing over the surface of the oil a lighted match until the oil starting to vaporize, the vapor ignites with a flash.

By repeating this test till the surface of the oil catches fire, we obtain the fire point or fire temperature.

It is generally inferred that the flash point being more or less an indication of the temperature at which an oil begins to decompose, would naturally indicate whether an oil is suitable or not for high temperature work. But it is also more or less evident that the flash and fire temperature is very much different at the various pressures in the cylinder as compared with the flash and fire temperature at atmospheric pressure because in the cylinder, the oil being, so to say, intimately mixed with steam, its chemical composition might be somewhat changed. The open flash and fire temperatures are given, as are all the other physical and chemical constants, as a possible and probable means of identifying the oils.

According to their flash points the oils ranks as follows:

TABLE 2.

Oil	Flash Temp.	Fire Temp.	Difference
D	568° F	616° F	48° F
F	568°	605°	37°
C	559°	606°	47°

B	553°	602°	49°
G	546°	610°	64°
A	533°	602°	69°
I	493°	564°	71°
E	487°	519°	32°
H	478°	514°	36°

It should be noted from the above table, that with the exception of oils D, C, A, I, E and H, which occupy the same rank in the flash and fire points, oil B is the fourth in the flash point and ranks the sixth in the fire test; oil F stands the second in the flash and the fourth in the fire test, while oil G is the fifth in the flash and second in the fire test. There is no apparent reason for these oils to behave in this manner.

Viscosity. The viscosity or the resistance of the oils to flow at various temperatures was measured by means of a "home made" electric viscosimeter.

This viscosimeter was made of a copper cup, fitted at its bottom with a standard nozzle, and around which was wound a resistance unit of german silver wire, the turns and layers of resistance wire being properly insulated from each other and from the cup.

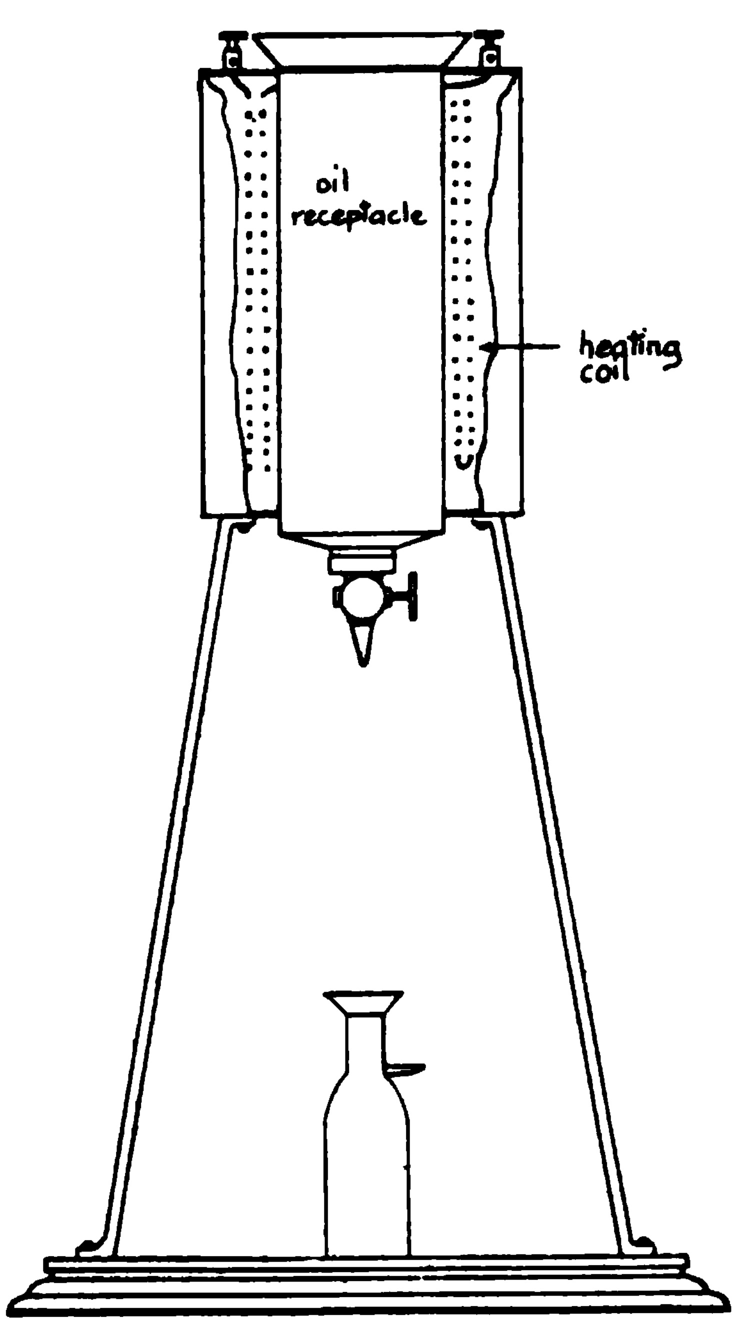

Fig. 2.

A maximum electric current of of 1.5 amperes was allowed to flow through the resistance unit, and the heat generated was sufficient to bring the oil in the cup to a temperature of 400° F in about 8 minutes. The control of temperature was obtained by varying the current in the resistance unit by means of suitable rheostat.

A sketch of this viscosimeter is shown in Figure 2.

The comparative viscosity of the oils tested are given in the following table for temperatures of 212° F, and 327.8° F (corresponding to 100 pounds steam pressure), the viscosity of water at 25° C (77° F) being taken as unity.

TABLE 3.

Oil	Viscosity At 212° F	Viscosity At 327.8° F
C	4.00	1.50
A	3.18	1.37
F	2.94	1.46
B	2.88	1.42
I	2.80	1.44
D	2.62	1.37
H	2.60	1.44
E	2.40	1.25
G	2.32	1.25

It is easily seen from the above table that at higher temperatures, the viscosity of all the oils tested approach the viscosity of water, and also that the oils do not rank in the same order for the higher temperature as they do for the temperature of 212°F.

CHEMICAL CONSTANTS OF THE OILS.

The determination of the acidity, saponification number, iodine absorption number, and per cent animal and vegetable fats were determined in the Dairy Research Laboratory by Mr. H. F. Yancey through the courtesy of Mr. L. S. Palmer, Dairy Chemist.

Acidity. The method used to determine the acidity is the one given by Allen†, and is as follows:

Weigh about 15 grams of oil into a 200 c c. Erlenmeyer flask. Add 50 c. c. of 95 per cent alcohol which has been neutralized with a weak solution of caustic solution using phenolphthalein as indicator, and heat to boiling. Agitate the flask thoroughly in order to dissolve the free acids as completely as possible. Decant the solution through a filter, and collect the filtrate in an Erlenmeyer flask. Repeat this operation six or seven times in order to get all of the free acid into the filtrate. Titrate hot with tenth normal alkali,‡ agitating thoroughly until the pink color persists after vigorous shaking.

The results are expressed either as percentage oleic acid or as acid value, that is, the number of milligrams of potassium hydroxide required to neutralize the free acids contained in one gram of oil tested.

It was found necessary to filter off the alcoholic solution from

†Allen, Commercial Organic Analysis, 3d Ed.

‡One cubic centimeter of tenth normal alkali is equal to 0.0282 grams of oleic acid.

the insoluble oil, because the dark color of the oil obscured the endpoint of the titration.

Saponification Number. The saponification number is the number of milligrams of potassium hydroxide required to saponify one gram of oil.

The method used for its determination is the official method, as given in Bulletin No. 107 (revised) U. S. Dept. of Agriculture, and is as follows:

Preparation of reagents:

1. Alcoholic Potash Solution.—Dissolve 40 grams of chemically pure potassium hydroxide in one liter of 95 per cent redistilled alcohol. The solution must be clear and the potassium hydroxide free from carbonates.

2. Standard Acid Solution.—Prepare accurately half normal solution of hydrochloric acid.

3. Indicator.—Dissolve 1 gram of phenophthalein in 100 c.c. of 95 per cent alcohol.

Determination:

Weigh about 10 grams of oil into a 300 c. c. Erlenmeyer flask. Run in 50 c. c. of the alcoholic potash solution, put on steam bath, and connect with reflux condenser. Allow to remain on steam bath for three hours with occasional shaking. Filter through paper, and wash unsaponifiable matter with hot alcohol until one drop of the filtrate from the filter shows no alkalinity to phenophthalein. Titrate the hot filtrate against half normal hydrochloric acid using phenolphthalein as indicator.

Conduct two or three blank experiments to determine the amount of alkali added to each sample in terms of the acid. To obtain the saponification number subtract the number of cubic centimeters of hydrochloric acid to neutralize the excess alkali after saponification from the number of cubic centimeters necessary to neutralize the 50 c. c. added; multiply the result by 28.06 (the number of milligrams of potassium hydroxide equivalent to 1 c. c. half normal acid) and divide by the number of grams of oil in the sample.

The unsaponifiable matter in the oils tested had to be separated from the solution, because its presence obscured the end point of the titration.

Iodine Absorption Number. The method used for the determination of the iodine absorption number of the oils is the Hübl official method as given in Bulletin No. 107 (revised) U. S. Dept. of Agriculture.

Preparation of Reagents:

1. Hübl's Iodin Solution.—Dissolve 26 grams of pure iodin

in 500 c. c. of 95 per cent alcohol. Dissolve 30 grams of mercuric chlorid in 500 c. c. of 95 per cent alcohol. Filter the latter solution if necessary, and mix the two solutions. Let the mixed solutions stand twelve hours before using.

2. Decinormal Sodium Thiosulphate Solution.—Dissolve 24.8 gr. of chemically pure sodium thiosulphate, freshly pulverized as finely as possible and dried between filter or blotting paper, and dilute with water to 1 liter at the temperature at which the titration is to be made.

3. Starch Paste.—Boil 1 gram of starch in 200 c. c. of distilled water for 10 minutes and cool to room temperature.

4. Solution of Potassium Iodid.—Dissolve 150 grams of potassium iodid in water to make up 1 liter.

5. Decinormal Potassium Bichromate.—Dissolve 4.9083 grams of chemically pure potassium bichromate in distilled water and bring the volume up to 1 liter at the temperature at which the titrations are to be made. The bichromate solution should be checked against pure iron.

Determination:

1. Standardizing the Sodium Thiosulphate Solution.—Place 20 c. c. of the potassium bichromate solution, to which has been added 10 c. c. of the solution of potassium iodid, in a glass stoppered flask. Add to this 5 c. c. of strong hyrochloric acid. Allow the solution of sodium thiosulphate to flow slowly into the flask until the yellow color of the liquid has almost disappeared. Add a few drops of the starch paste, and with constant shaking continue to add the sodium thiosulphate solution until the blue color just disappears.

2. Weigh about one half gram of the oil on a small watch crystal; heat and mix thoroughly; pour into another watch crystal and allow to cool. Introduce the watch crystal (containing the oil) into a wide-mouth 16 ounce bottle with ground glass stopper.

3. Absorption of Iodin.—Dissolve the oil in the bottle in 10 c. c. of chloroform. After complete solution has taken place, add 40 or 50 c. c. of the iodin solution. Place the bottle in a dark place and allow to stand, with occasional shaking, for eight hours. This time must be closely adhered to in order to get good results. The excess of iodin should be at least twice as much as is absorbed.

4. Titration of the Unabsorbed Iodin.—Add 20 c. c. of the potassium iodid solution and shake thoroughly, then add 100 c. c. of distilled water to the contents of the bottle, washing down any free iodin that may be noted on the stopper. Titrate the iodin with the sodium thiosulphate solution which is added gradually, with constant shaking, until the yellow color of the solution has almost

disappeared. Add a few drops of starch paste and continue the titration until the blue color has entirely disappeared. Toward the end of the reaction, stopper the bottle and shake violently, so that any iodin remaining in solution in the chloroform may be taken up by the potassium iodid solution.

5. Standardizing the Iodin Solution by Thiosulphate Solution.—At the time of adding the iodin solution to the oil employ two bottles of the same size as those used for the operations described under paragraph 3, 4, and 5, the extra bottle being used for standardizing the iodin solution, no oil being present. The blank experiments for standardizing must be made each time the iodin solution is used. Great care must be taken that the temperature of the solution does not change during the time of the operation, as alcohol has a very high coefficient of expansion, and a slight change of temperature makes an appreciable difference in the strength of the solution.

Per cent of Animal and Vegetable Oils. According to Sherman's Organic Analysis pp. 147 and 192, if any oil has a low saponification number and also a low iodin number, it may safely be assumed that the oil in question is composed of a large percentage of mineral oil and a correspondingly small percentage of animal and vegetable fats, and if such is the case, the percent fatty oils can be estimated with sufficient accuracy for most purposes from the saponification number, since fatty oils which are likely to be present in mixed lubricants do not vary greatly in their saponification number.

In estimating the percent animal and vegetable fats present in the oils tested a saponification number of 190 was used.

The following table shows the results of the above described tests:

TABLE 4.

Oil	Free acid value	Free oleic acid	Saponif. number	Iodine number	Animal and vegetable fats
B	trace	trace	8.5	14.56	4.47
A	.133	.097	12.2	15.32	6.42
G	.125	.087	14.3	14.32	7.52
I	.575	.405	17.1	11.36	9.08
D	.238	.169	18.4	13.70	9.25
F	.098	.073	21.0	12.80	11.05
C	.176	.127	25.2	12.21	13.26
E	.367	.280	34.9	16.37	18.38
H	.362	.254	35.8	15.90	18.84

The above table shows that all oils tested have a very low acid

value, also low saponifications and iodin numbers. Naturally these facts indicate the high percentage of mineral oil and the low percentage of animal and vegetable oil.*

FRICTION TESTS.

The following description of the friction testing apparatus is given by Mr. A. E. Flowers, who designed it, in Vol. 2, No. 2 of the Engineering Experiment Station Series:

"The method of measurement (of the friction coefficient) . . . was to measure electrically the input to a motor and to subtract the motor losses. The motor was provided with a crank disk and connecting rod, driving two pistons fastened on the opposite ends of a piston rod with a steam space, and a pocket for collecting condensation between pistons." . . . Two Detroit one pint lubricators "connected to steam pipes entering the cylinder near the ends, just inside the inner portions of the cylinder" fed the oil to the cylinder. "The use of two pistons with a steam space between them prevents the steam from doing any work itself or having work done on it. Each end of the connecting rod was fitted with Hess-Bright ball bearings so that its friction is negligible compared with that of the pistons." . . . . "The cylinder bore is 5 inches and each piston has 3 standard type, cast iron piston rings, the width of each being .2175 inches. These rings gave a pressure of about 3.23 pounds per inch of circumference and 14.92 pounds per square inch after being worked to a fit. As the cylinder ends are open, only one face of the piston is subjected to steam pressure and temperature, the other face being subject to conditions corresponding to those of the exhaust of a non-condensing engine."

This method of measuring the friction coefficient in a steam cylinder by means of an electric motor is not entirely new. Mr. F. C. Wagner has used it in making friction tests of a locomotive slide valve. (Proc. A. S. M. E. Vol. XXI, 1900, p. 242.)

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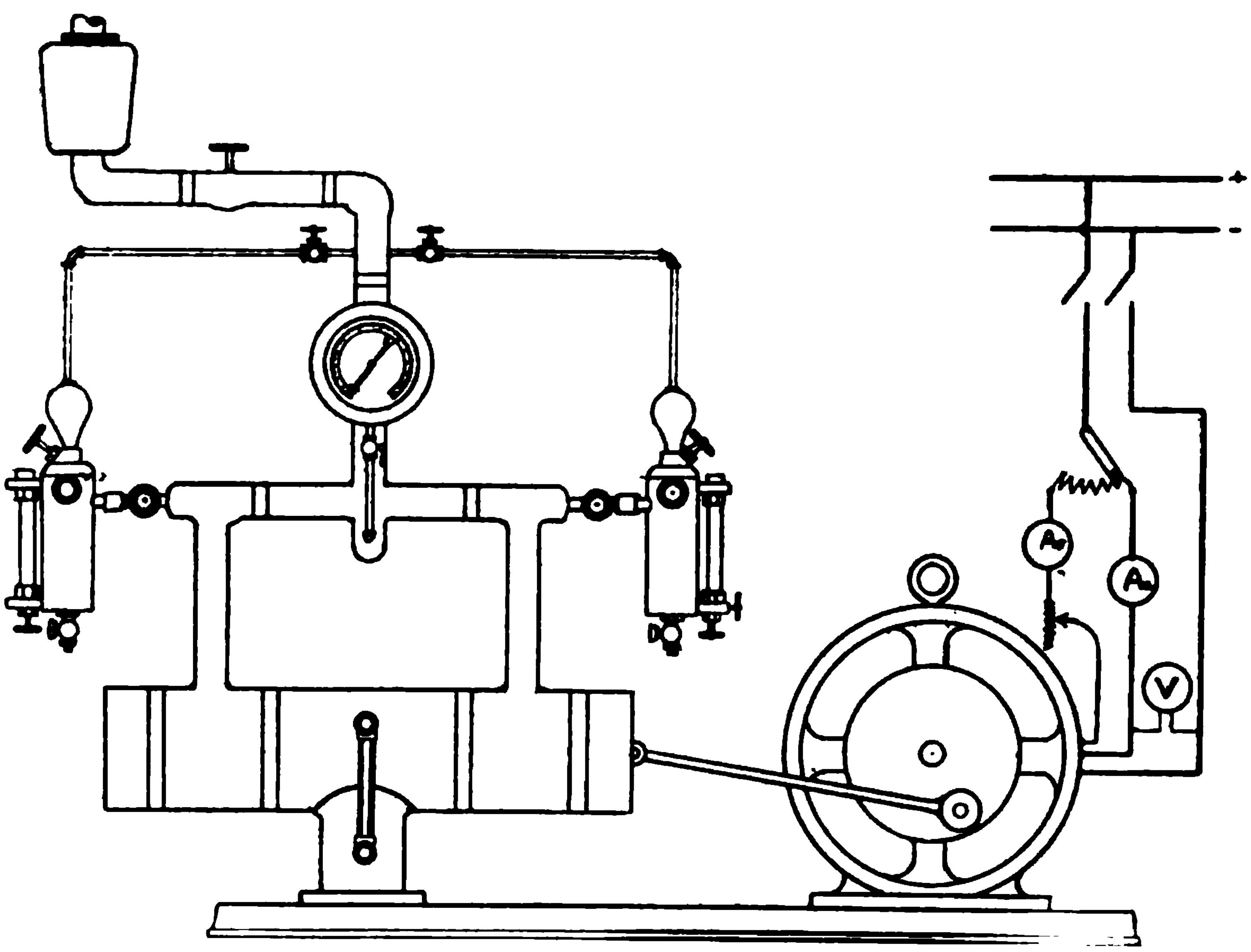
*For more detailed information on the chemical analysis of cylinder oils see A. C. Wright, The Analysis of Oils; Stillman, Engineering Chemistry; A. H. Gill, Oil Analysis; Sherman's Organic Analysis.

The following sketch shows diagramatically the testing apparatus above described.



APPARATUS FOR MAKING LUBRICATION TESTS.

Fig. 3.

The steam, after passing through a steam separator and reducing valve, is admitted into the cylinder, the steam pressure being obtained by means of an Ashcroft standard gauge.

The motor supplying the motive power was an Interpole motor made by the Electro-Dynamic Co. of Bayonne, N. J., and rated V. 110—H. P. ½—R. P. M. 400-1600 and throughout all the tests was run on constant supplied voltage of 90 volts and with a constant excitation of .300 amperes. the speed of the motor varying slightly from 620 revolutions per minute under various steam pressures in the cylinder, and various conditions of oil feed thus giving an approximate piston speed in the cylinder of about 520 feet per minute.

This motor has been carefully calibrated for losses by Mr. Flowers before and recalibrated by the writer after the tests were made, the difference in results being of no consequence.

Each of the oils has been tested under varying pressures up to or a little over 100 pounds per square inch steam pressure, and with three different conditions of feed, namely 10, 20 and 30 seconds to the

drop, that is six, three and two drops to the minute. The feed of the oil was maintained as far as possible constant during each test.

The following readings were taken:

Voltage supplied to the motor, constant at 90 volts.

Field current of the motor, constant at .300 amperes.

Armature current of the motor, variable, depending upon kind of oil used, feed, and steam pressure.

Oil feed, in seconds to the drop.

Steam pressure in pounds to the square inch, gauge.

The temperature of the rubbing surfaces, by means of thermometers in "pockets" within 1-16 of an inch of the inner cylinder wall and opposite the mid stroke position.

Calculations.. The calculations were made as follows:

Let **E** = voltage supplied to the motor armature.

I = armature current for any reading during a test.

R = resistance of the armature of motor at the working temperature.

L = friction and iron losses of the motor corrected for armature reactions occuring for an armature current (I).

Then

EI = power supplied to the motor armature in watts.

$EI - (I^2R + L)$ = watts power output of the motor, supplied to the cylinder to overcome the friction. In terms of horse power this amounts to

$$\frac{EI - (I^2R + L)}{746} \text{ Horse Power.}$$

If **F** = drag force and

V = speed of piston in feet per minute, then

$$H.\ P. = \frac{F \times V}{33000}$$

Hence the drag force $F = 33000 \dfrac{EI - (I^2R + L)}{746V}$

Now if **f** = friction coefficient, and

P = normal pressure exerted on the cylinder walls.

$$f = \frac{F}{P} = 33000 \frac{EI - (I^2R + L)}{746\,V\,P}$$

Results. The results of the friction tests above described are shown graphically in the following nine plates, Figs. 4 to 12 inclusive, each plate representing the variation of the friction coefficient of one oil with the steam pressure in pounds per square inch, and

also with the corresponding temperature in degrees Fahrenheit. The three curves on each plate are for three different conditions of feed, the upper curve being for a feed of 30 seconds to the drop, (or 2 drops to the minute), the middle curve for a feed of 20 seconds to the drop (or 3 drops to the minute), and the lower curve for a feed of 10 seconds to the drop (or 6 drops to the minute). Each of these curves is a composite curve of at least three different sets of observations under similar conditions of feed. For some oils as many as six different sets of observations were taken to check and thus insure uniform results.

An analysis of the curves shows that for most of the oils tested, the friction coefficient decreases with increase of the quantity of oil supplied, and also a decrease in the friction coefficient under the three different conditions of feed with increase of steam pressure, the friction coefficient becoming more or less constant with higher steam pressures.

This last statement is especially true for oils A, B, E, and G, as seen from curves Figs. 4, 5, 8 and 10.

The other oils behave in a rather peculiar manner. Thus for oil C the above statement is true only for feeds of 10 and 20 seconds to the drop, while for a feed of 30 seconds to the drop, with the exception of a slight decrease up to 50 pounds per square inch of steam pressure, the friction coefficient is almost constant at .0640.

A similar but more pronounced result was obtained for oils F and H, the coefficient of friction being .0660 and about .0510 for the two oils respectively at feeds of 30 seconds to the drop for each oil.

A still more pronounced result of a similar nature was obtained for oil D, for which the friction coefficient is constant at about .0600 and .0560 for 30 and 20 seconds to the drop respectively.

The results for oil I are still more peculiar in as much, that while the friction coefficient for a feed of 30 seconds to the drop decreases with the steam pressure as it does for the other oils at higher feeds, the friction coefficient for feeds of 10 and 20 seconds to the drop apparently increases with the steam pressure, as seen from the curves in Fig 12.

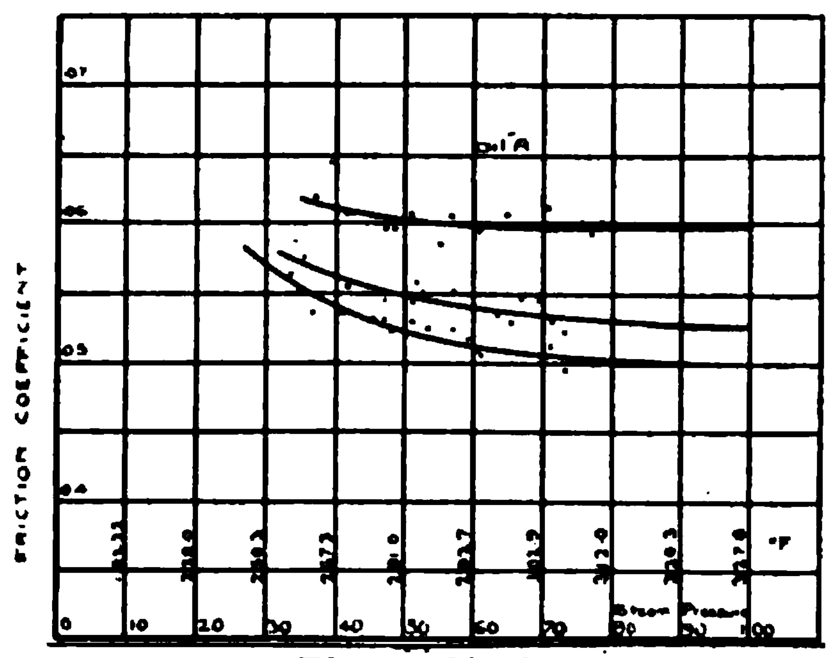


Fig. 4, Oil A.

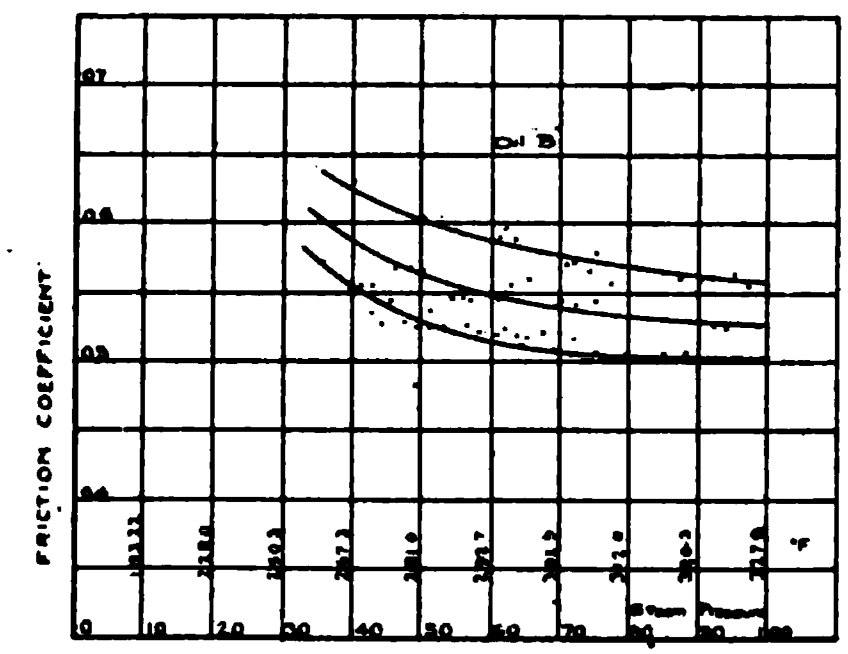


Fig. 5, Oil B.

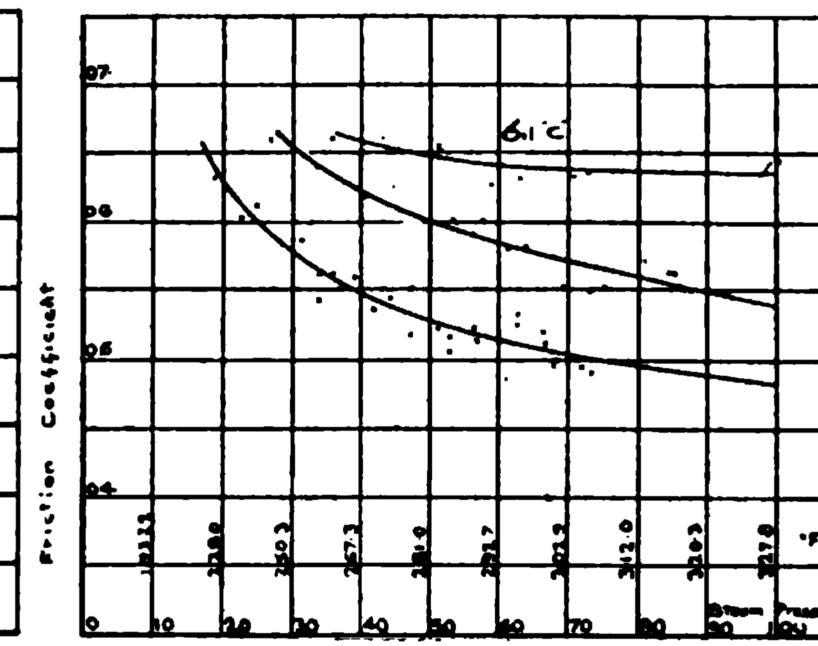


Fig. 6, Oil C.

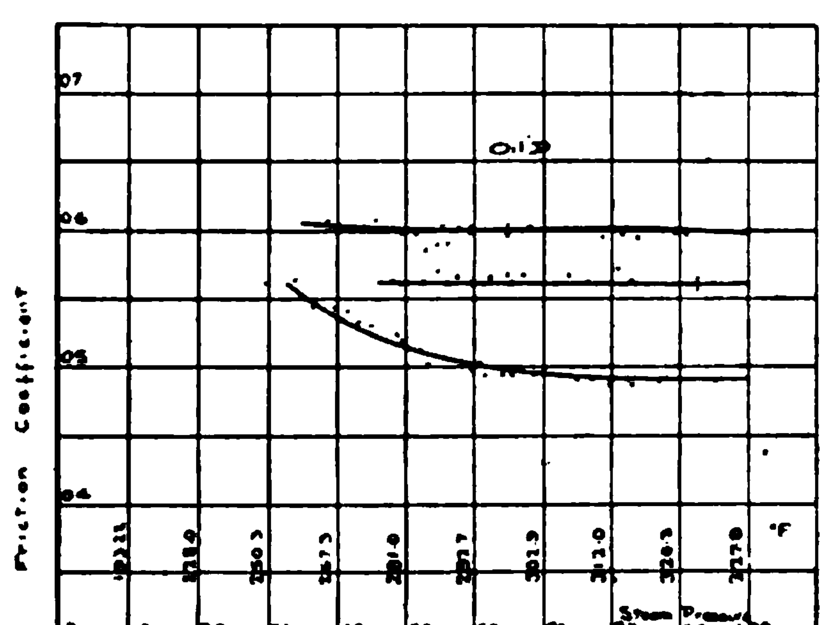


Fig. 7, Oil D

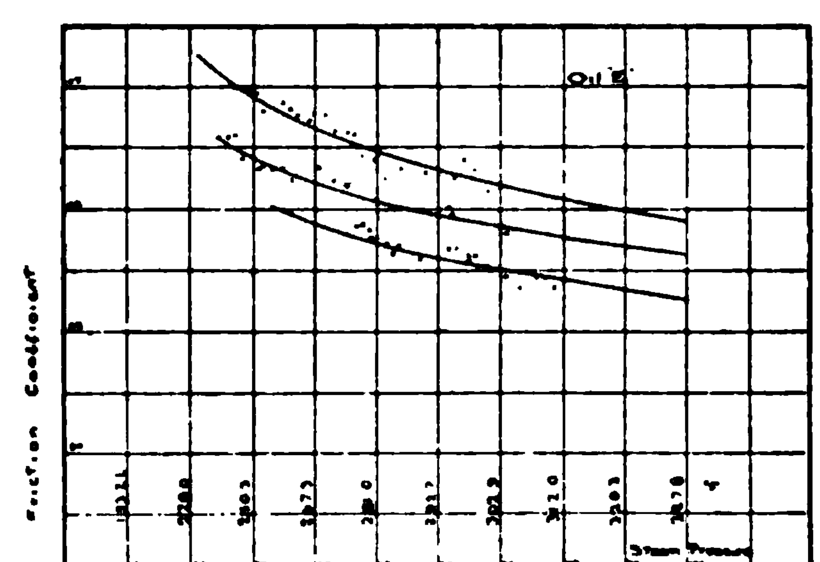


Fig. 8, Oil E.

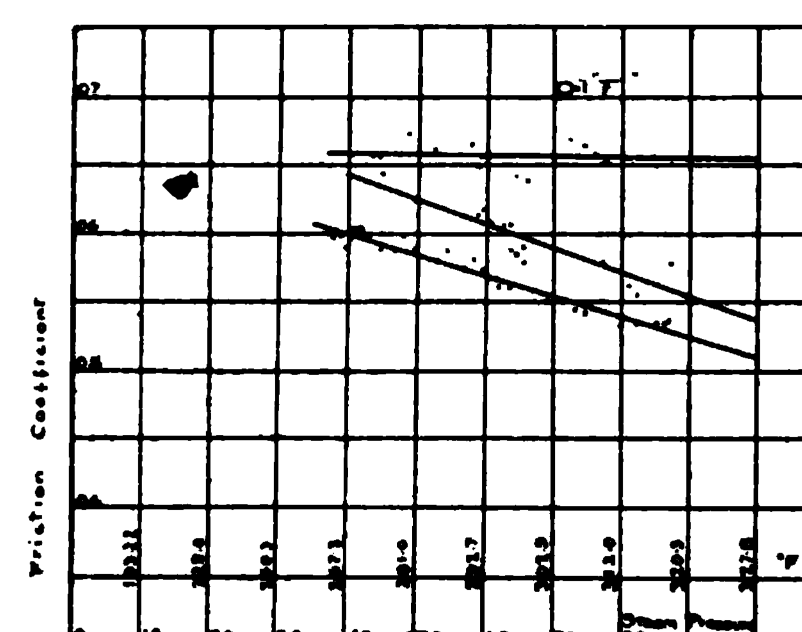


Fig. 9, Oil F.

VARIATION OF THE FRICTION COEFFICIENT WITH STEAM PRESSURE AND TEMPERATURE.

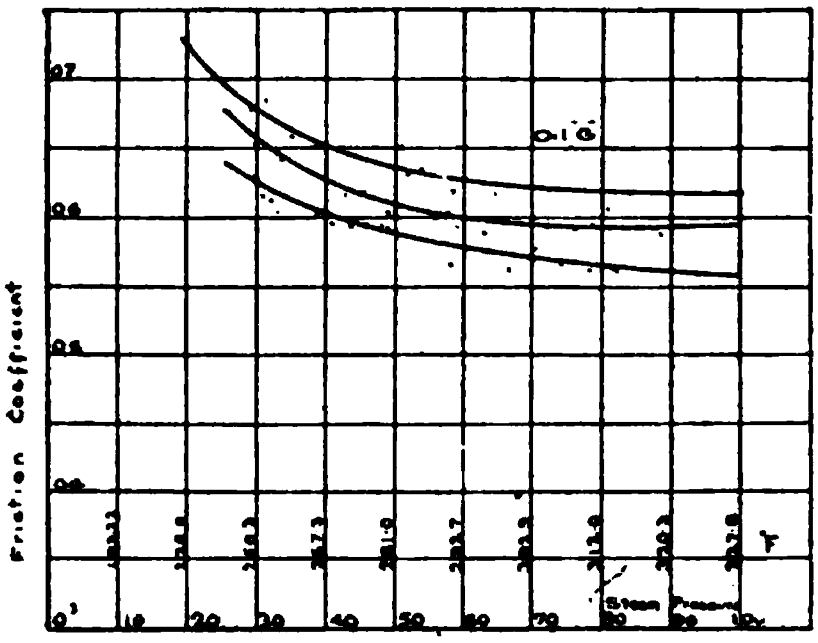


Fig. 10, Oil G.

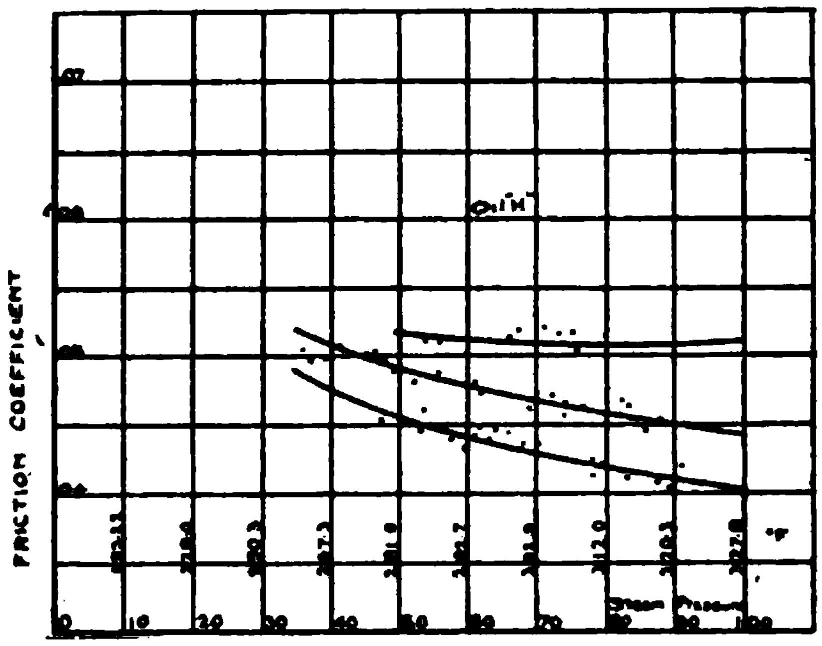


Fig. 11, Oil H.

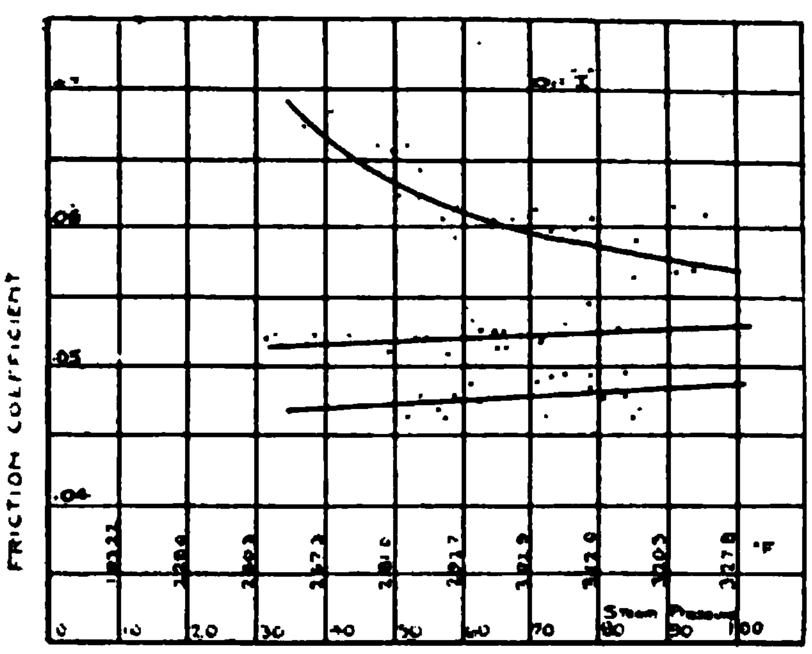


Fig. 12, Oil I.

VARIATION OF THE FRICTION COEFFICIENT WITH STEAM PRESSURE AND TEMPERATURE

According to the value of friction coefficient, based on the same feed in seconds to the drop and for the same steam pressure, the oils rank as shown in the following tables:

TABLE 5.

Steam Pressure, 60 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0439	H	.0472	H	.0510
I	.0474	I	.0520	B	.0588
D	.0500	A	.0539	D	.0600
C	.0511	B	.0550	A	.0600
A	.0511	D	.0560	I	.0610
B	.0517	C	.0582	G	.0626
E	.0560	E	.0596	E	.0632
F	.0570	G	.0598	C	.0640
G	.0572	F	.0608	F	.0660

TABLE 6.

Steam Pressure, 80 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0418	H	.0452	H	.0510
I	.0480	I	.0523	B	.0569
D	.0490	A	.0529	I	.0585
C	.0493	B	.0533	A	.0598
A	.0500	D	.0560	D	.0600
B	.0505	C	.0567	E	.0608
E	.0540	F	.0573	G	.0618
F	.0540	E	.0580	C	.0640
G	.0560	G	.0590	F	.0660

TABLE 7.

Steam Pressure, 100 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0404	H	.0438	H	.0510
I	.0485	B	.0525	B	.0558
C	.0485	A	.0526	I	.0567
D	.0490	I	.0528	E	.0591
A	.0495	F	.0535	A	.0598
B	.0502	C	.0542	D	.0600
F	.0510	E	.0572	G	.0618
E	.0528	D	.0560	C	.0640
G	.0560	G	.0590	F	.0660

It appeared to writer that a comparison of the lubricating qualities of the oils on the basis of the same rate of feed in drops per minute, is not entirely reasonable on account of the fact that different oils have different size drops. Therefore even though the feed in number of drops per minute is the same, the quantity by volume admitted into the cylinder will not be same, and as a consequence the comparison is not a true one.

The friction coefficients of the oils should be compared on the basis of the same quantity by volume and with that end in view experiments were carried out to determine the size in cubic centimeters of the drops of the oils tested under the same conditions of feed in drops per minute, and at the same temperature of the oil in the

lubricator as under the actual conditions of the friction tests described in the previous pages.

Size of Drops. The apparatus used to determine the size of the drops of the oils, was a lubricating cup, detached for this purpose from the friction testing apparatus, fitted with a graduated glass tube (a) filled with hot water, whereby the oil was warmed up to the proper temperature, and by means of which sufficient pressure was obtained to force the oil from the lubricating cup into another graduated glass tube (b), partially filled with water. The apparatus is shown in Fig. 13.

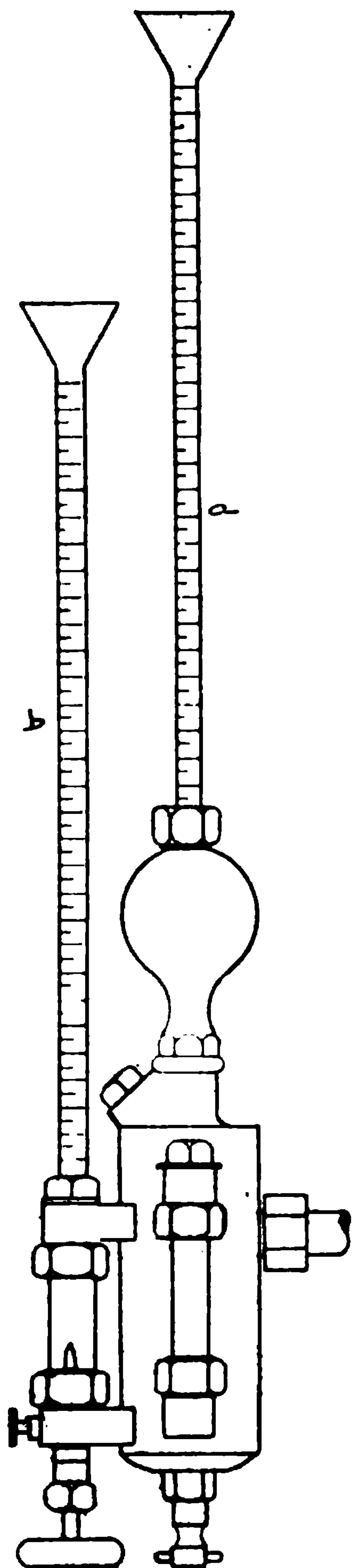


Fig. 13.

After adjusting the rate of feed to the required number of drops per minute, a certain counted number of drops of oil was let into the graduated glass tube (b) and their combined volume in cubic centimeters read.

The volume of the water in tube (a) which displaced the oil was also read, and as it is equal to the volume of oil displaced, the average value of these two volumes, namely that of the oil and that of the water displacing the oil divided by the number of drops, gave the size of the drop in cubic centimeters.

The average size of the drops of the oils, as measured by the above described method, is given in the following table:

TABLE 8.

Oil	Size of drops
A	.3124 c. c
B	.2423
C	.2142
D	.1911
E	.1653
F	.1482
G	.1418
H	.1184
I	.0722

From the size of drops, as given in the above table, and the rate of feed in drops per minute, the quantity of oil admitted into the cylinder for various rates of feed was calculated and the results embodied in the following curve (Fig. 14), where the volume per minute is plotted as a function of the rate of feed in seconds to the drop.

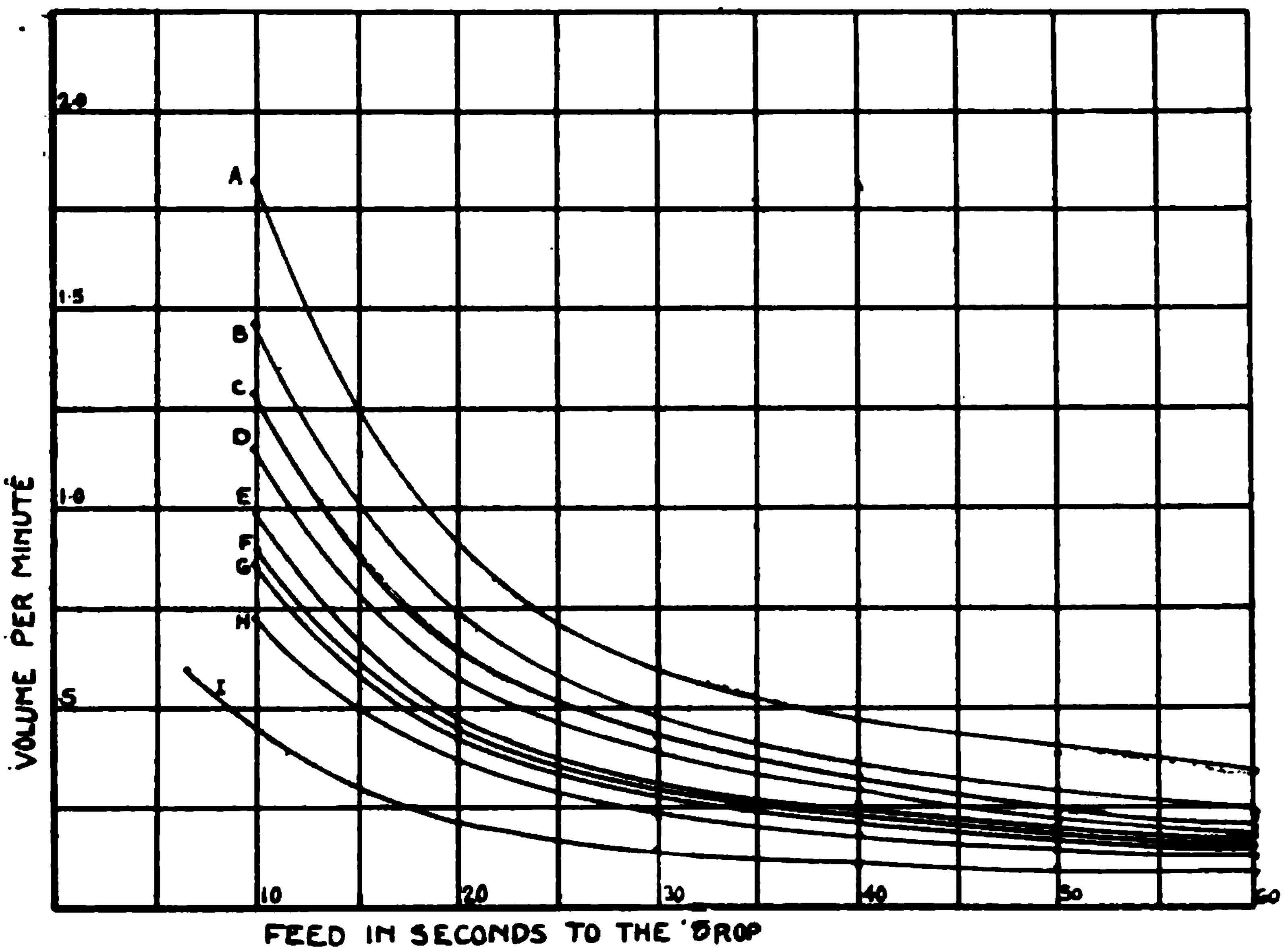


Fig. 14.

VARIATION OF THE FRICTION COEFFICIENT WITH RATE OF FEED IN SECONDS PER DROP.

In order to translate the results of the friction tests on the basis of equal rates of feed, in terms of equal volumes of oil admitted into the cylinder in unit time, we need besides the above curves showing the variation of the volume of oil with the rate of feed, also curves showing the variation of the friction coefficient with the rate of feed in seconds to the drop, or drops per minute.

Accordingly the following curves, Figs. 15 to 23, showing the friction coefficient as a function of the rate of feed in seconds to drop for constant pressure, were obtained from the friction coefficient curves plotted against steam pressure.

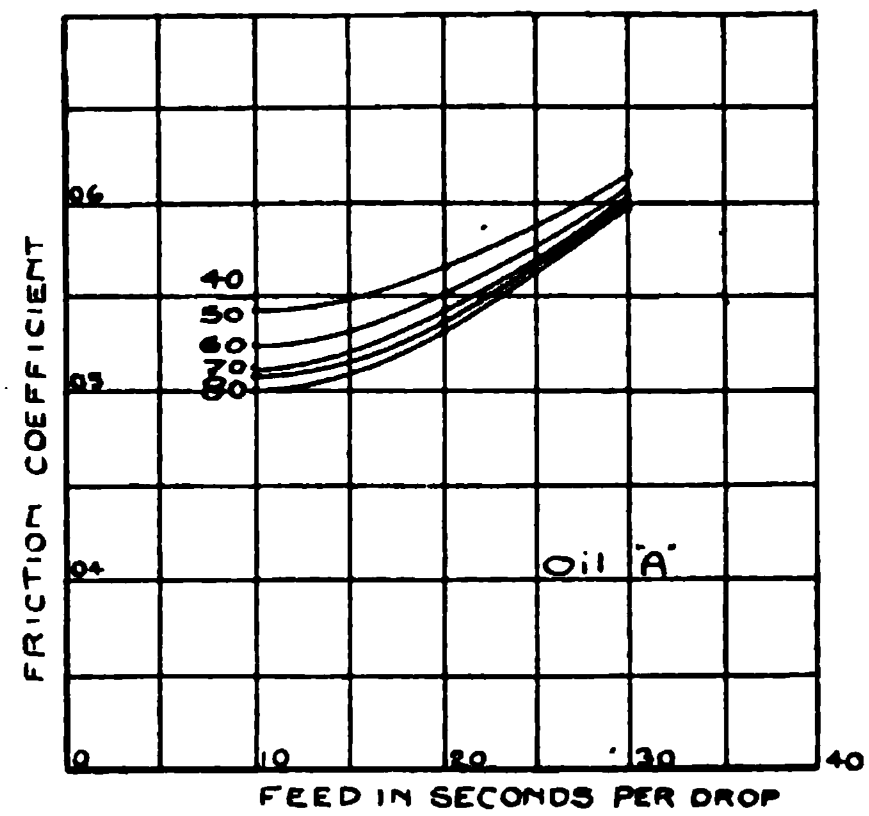


Fig. 15, Oil A.

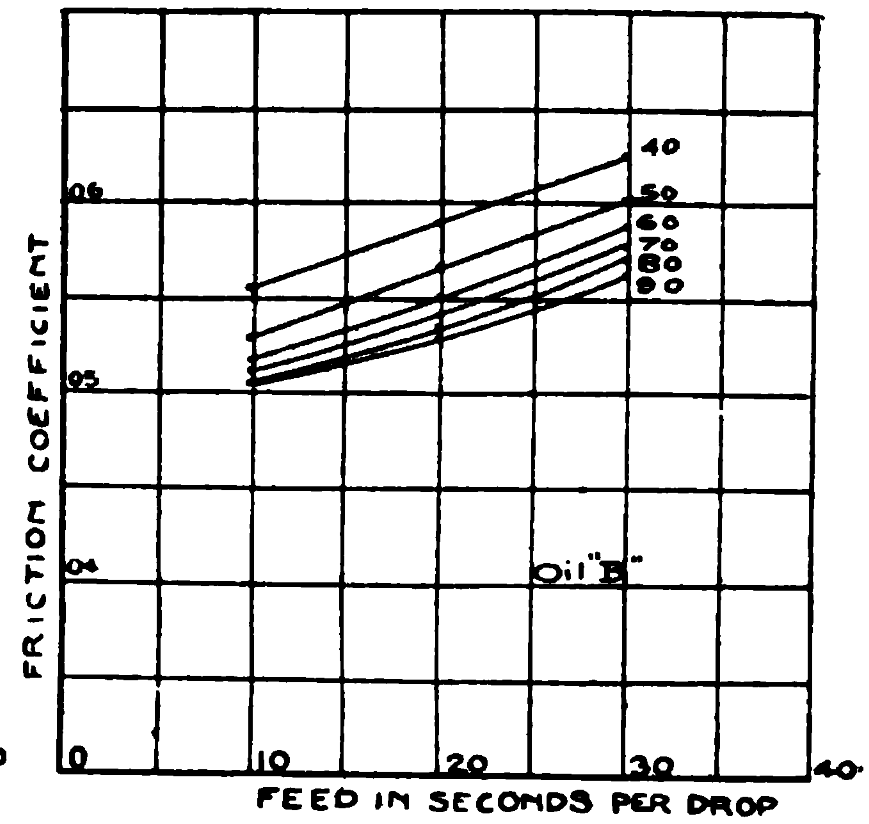


Fig. 16, Oil B.

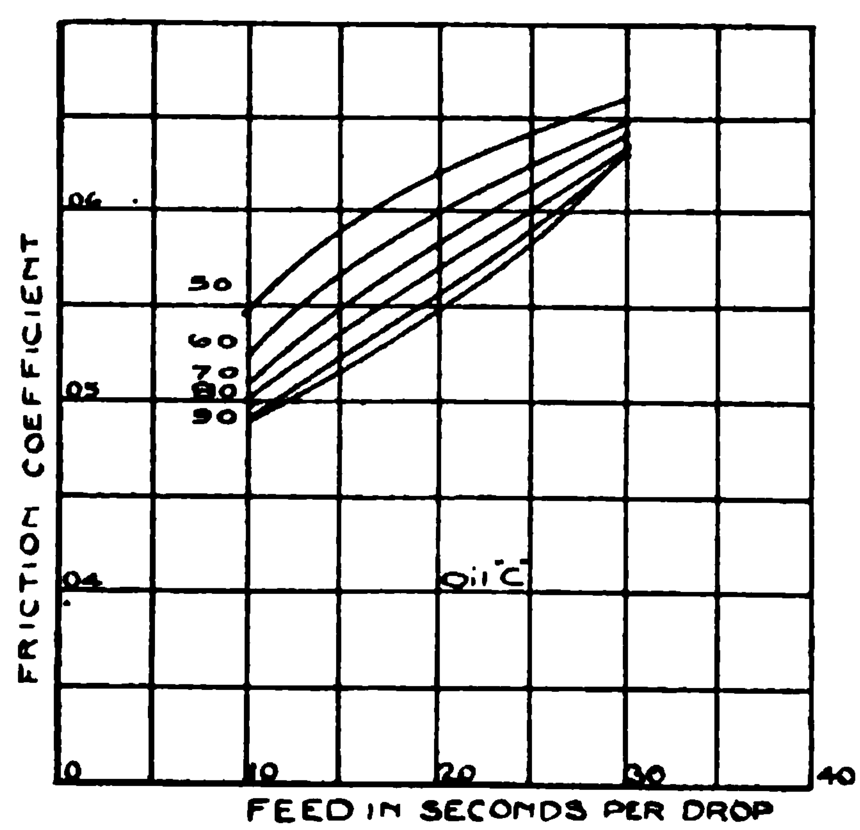


Fig. 17, Oil C.

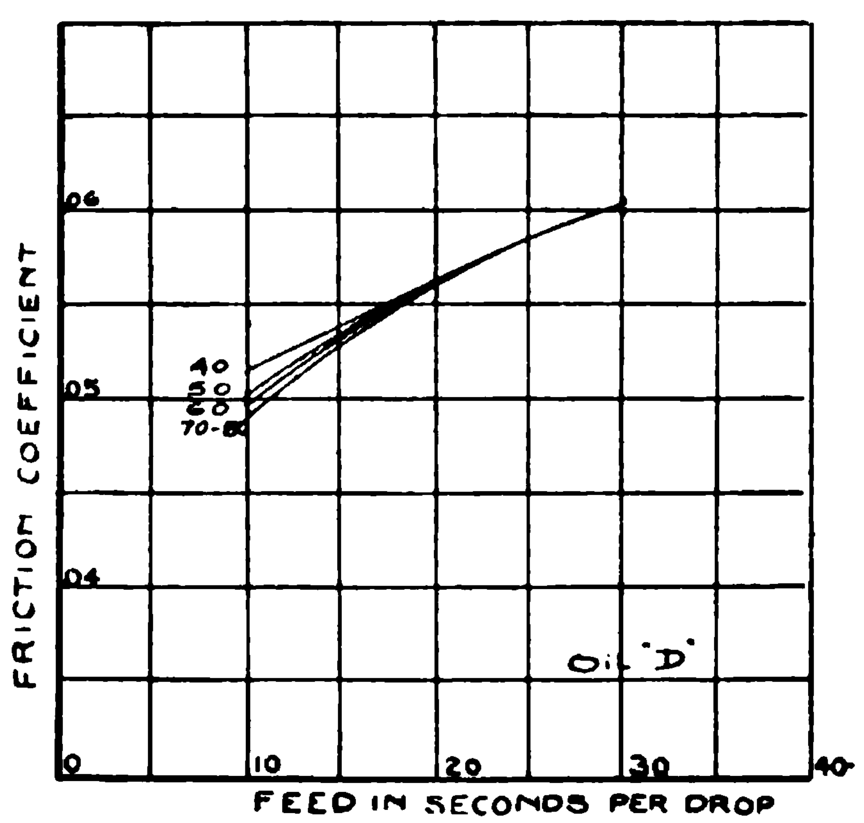


Fig. 18, Oil D.

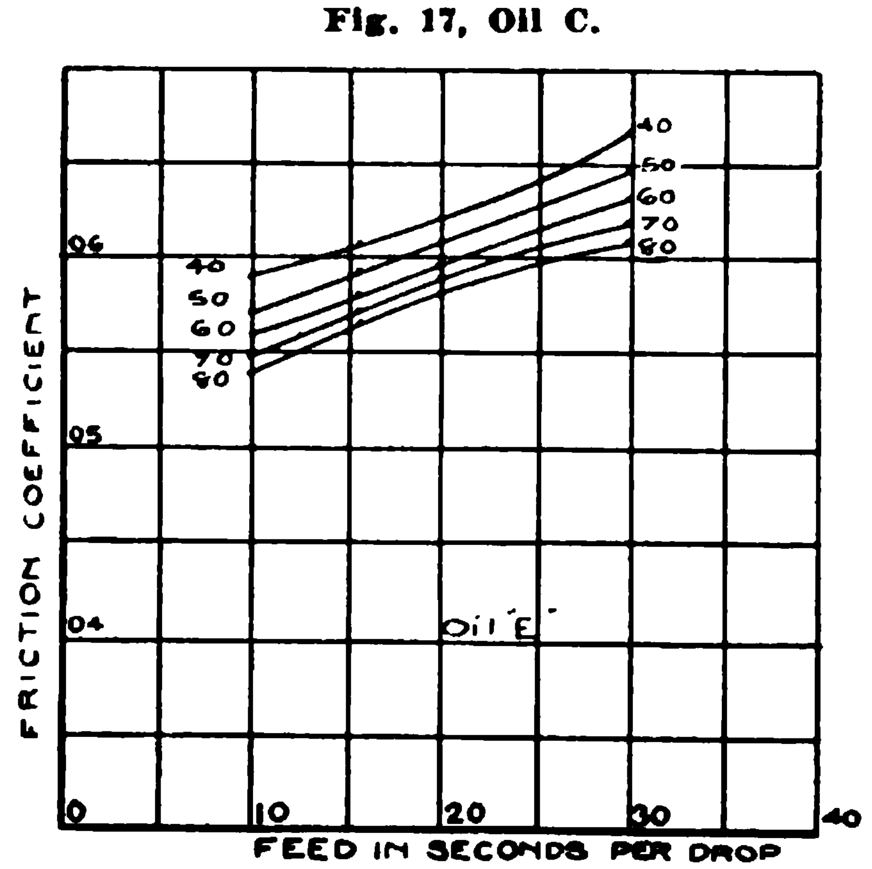


Fig. 19, Oil E.

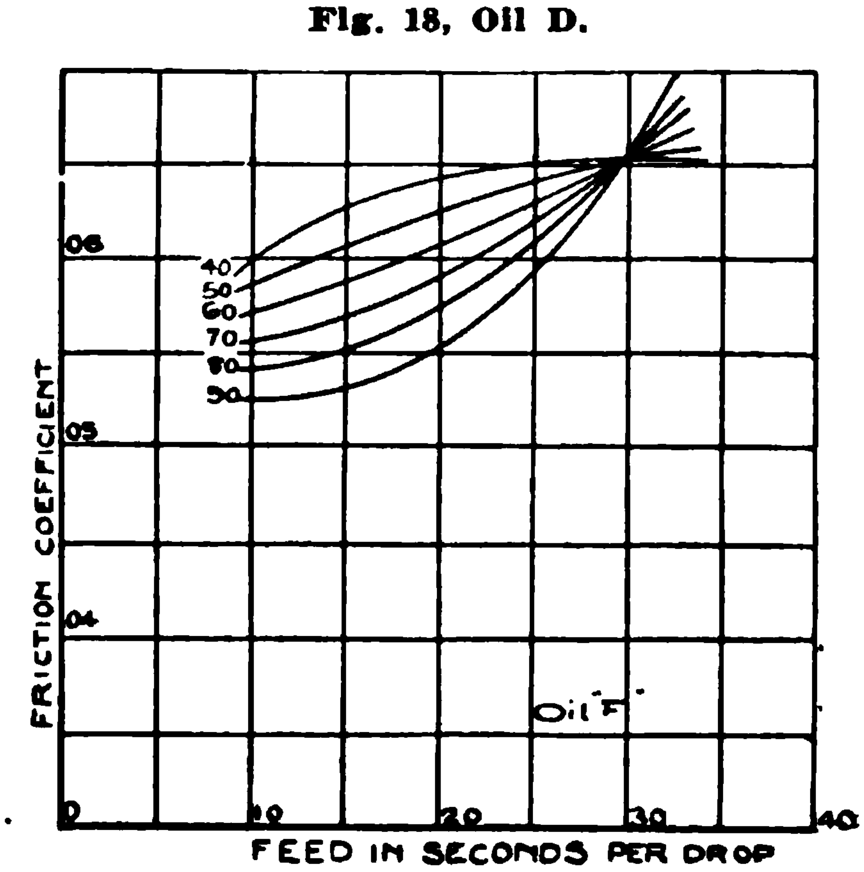


Fig. 20, Oil F.

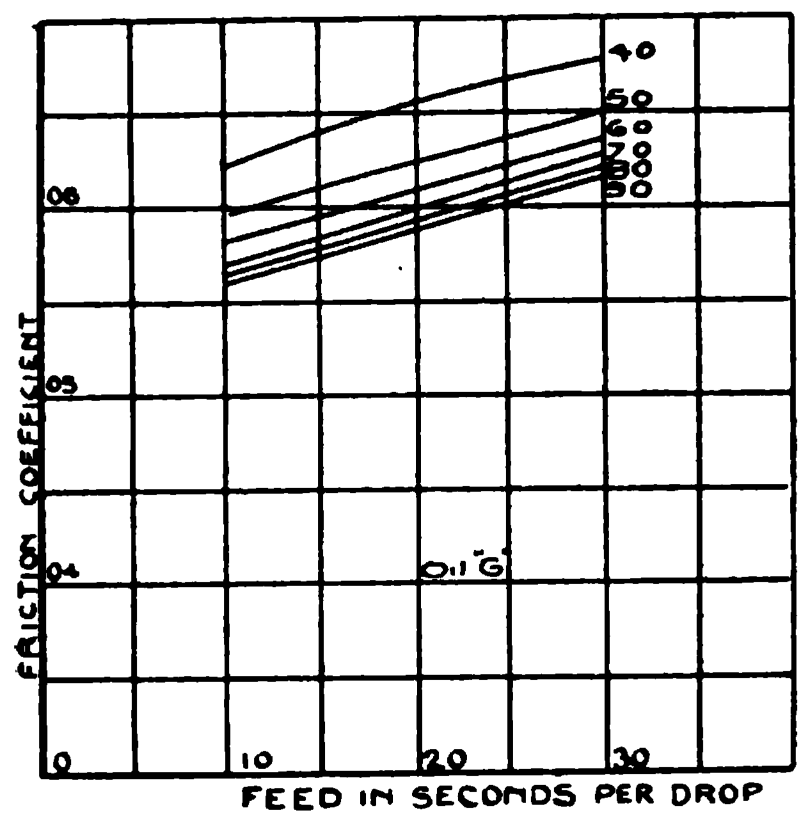


Fig. 21, Oil G.

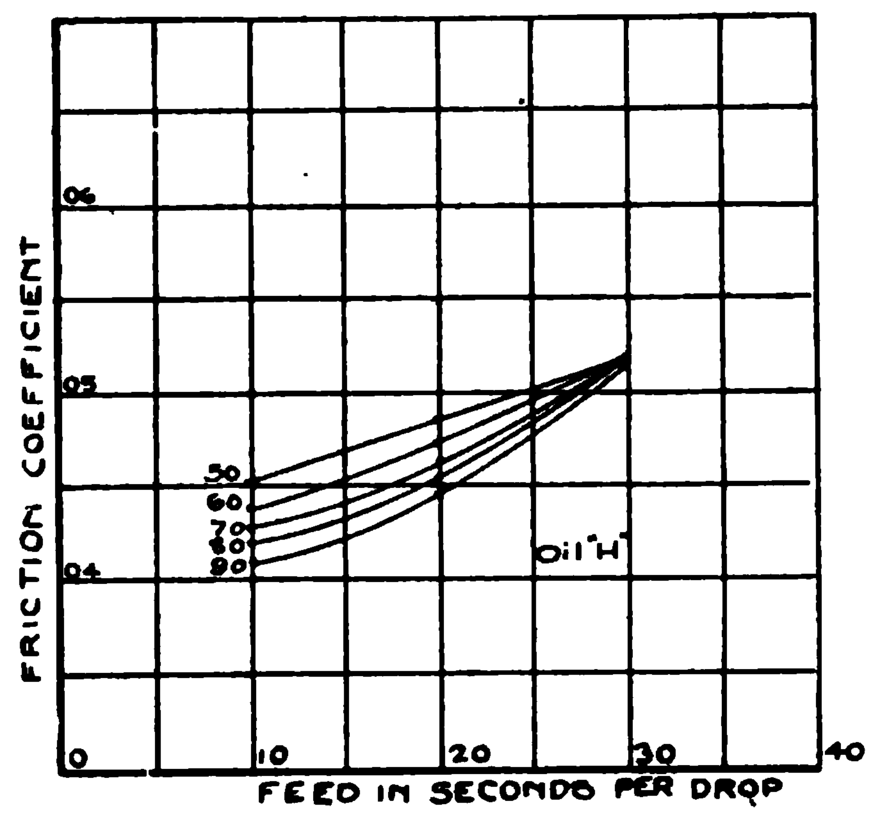


Fig. 22, Oil H.

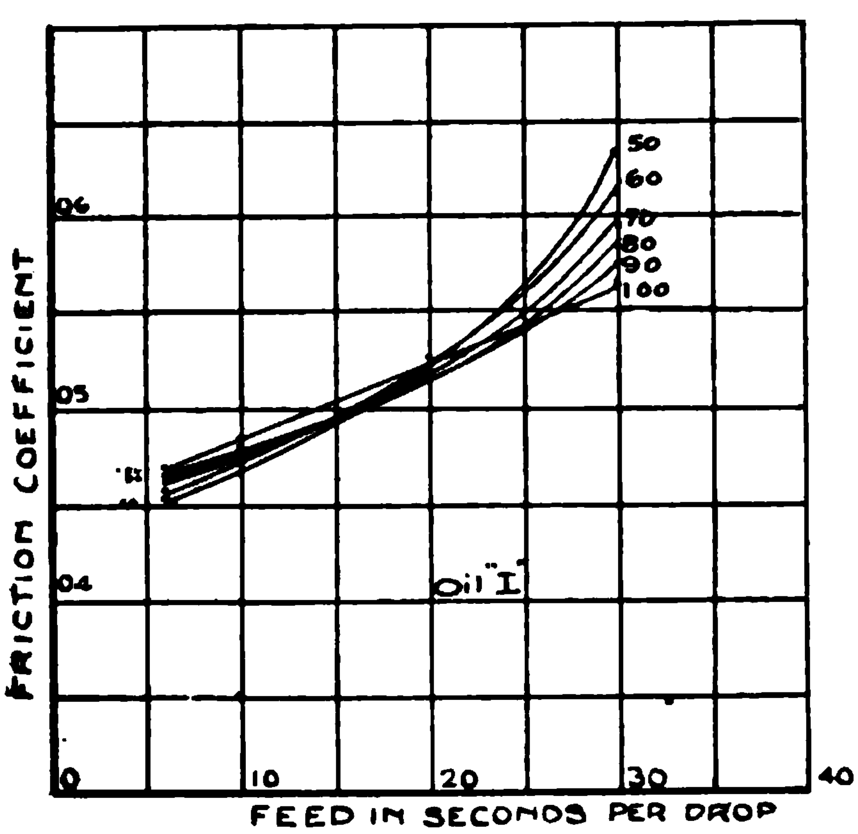


Fig. 23, Oil I.

VARIATION OF THE FRICTION COEFFICIENT WITH THE OIL FEED IN SECONDS PER DROP

These curves show certain peculiarities of the oils that are well worth some attention. Thus oils H and D while differing in many respects, have a more or less identical peculiarity, namely that the friction coefficient attains a constant value at a certain rate of feed, irrespective of the steam pressure. Oil H has a constant friction cofficient of .0520 at a feed of 2 drops per minute and oil D, a constant friction coefficient of .0560 at about 3 drops per minute.

Similarly oil F attains a constant friction coefficient of .0655 at a feed of 2 drops per minute, while the point of constant friction coefficient is not so well defined for oil I. However, these last two oils differ from oils D and H in the fact that for feeds higher

than the feed for constant friction, the friction coefficient is higher for higher steam pressures and lower for lower steam pressures, the reverse being true for lower rates of feed beyond that for the constant friction coefficient value.

These rather curious results were not obtained for the other oils tested.

A quantity of .60 cubic centimeters of oil, corresponding to 2 drops per minute for oil A, was arbitrarily chosen as a standard for which the friction coefficient of the oils should be compared on the basis of equal volumes of oil admitted into the cylinder per minute.

From the curves of figure 14 we find, that in order to supply this quantity of oil per minute, the various oils tested would have to be fed at the following rates:

TABLE 9.

Volume of Oil Admitted into the Cylinder per Minute = .60 c c.

Oil	Rate of feed seconds per drop.
A	30
B	24
C	21
D	19
E	16
F	15
G	14
H	12
I	7

Using these rates of feed and the curves showing the relation between the friction coefficient and the rate of feed in seconds to the drop, (figs. 15 to 23), we can then find the corresponding friction coefficient of the oils for various steam pressures at a constant feed of .60 cubic centimeters per minute.

The following table shows the comparative values of the friction coefficient on this basis:

TABLE 10.

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "A" 30 sec. per drop	Oil "B" 24 sec. per drop	Oil "C" 21 sec. per drop
40	0.0613	0.0601	0.0625
50	.0607	.0580	.0600
60	.0600	.0562	.0590
70	.0600	.0552	.0570
80	.0600	.0545	.0557
90	——	.0540	.0550
100	.0590	.0535	.0540

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "D" 19 sec. per drop	Oil "E" 16 sec. per drop	Oil "F" 15 sec. per drop
40	——	0.0608	0.0630
50	0.0557	.0593	.0609
60	.0555	.0581	.0587
70	.0555	.0575	.0570
80	.0555	.0569	.0552
90	.0555	——	.0532
100	.0555	.0555	.0512

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "G" 14 sec. per drop	Oil "H" 12 sec. per drop	Oil "I" 7 sec. per drop
40	0.0608	——	——
50	.0592	0.0460	0.0460
60	.0582	.0444	.0462
70	.0578	.0432	.0468
80	——	.0424	.0470
90	.0572	.0415	.0472
100	.0571	.0410	.0475

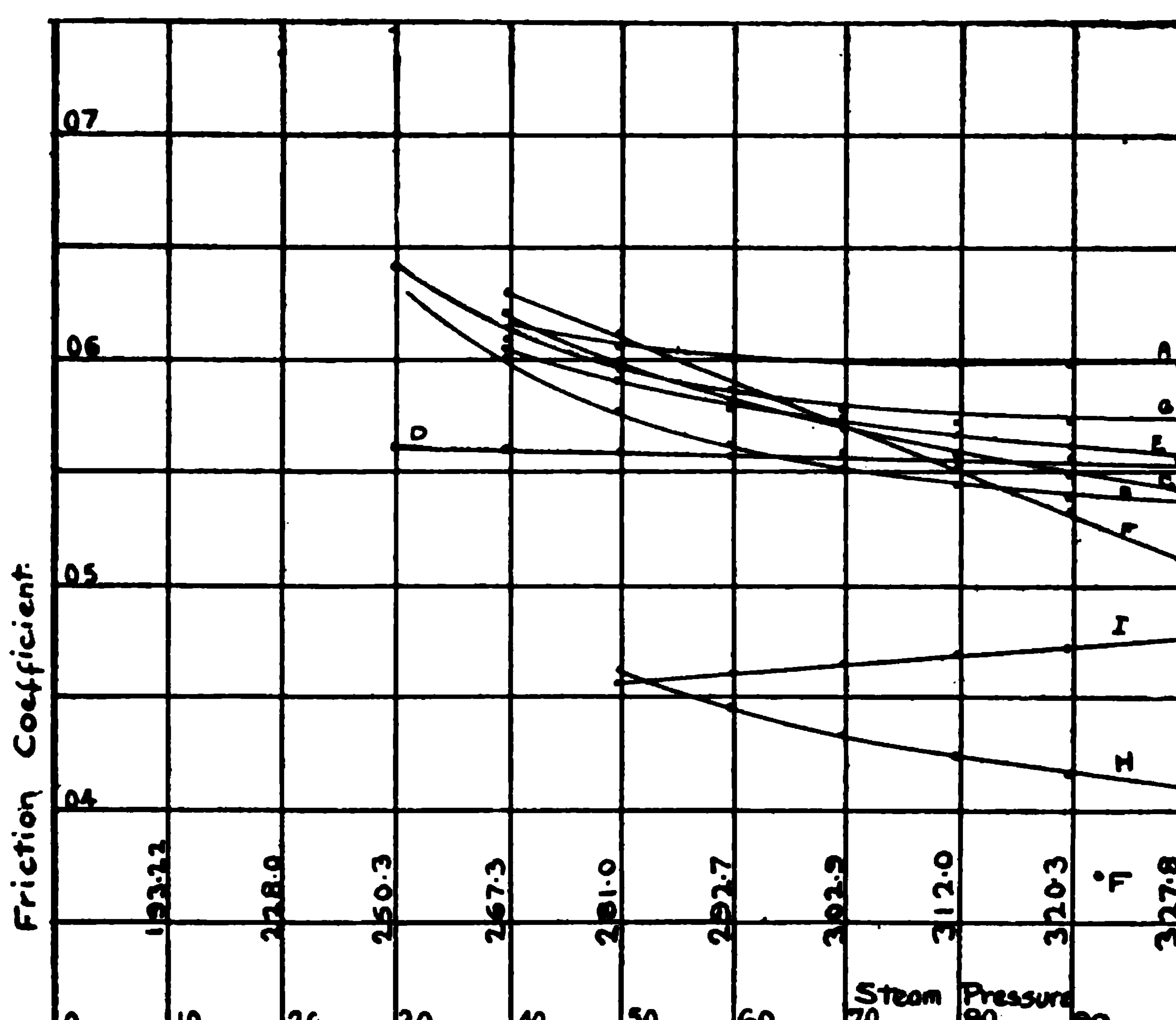


Fig. 24.

These results are also shown graphically in fig. 24. From these curves we can readily see that on the basis of the same quantity of .60 cubic centimeters of oil admitted into the cylinder per minute, the oils tested rank as follows for a steam pressure of 100 pounds per square inch.

TABLE 11

No.	Oil	Frict. Coeff.
1	H	.0410
2	I	.0475
3	F	.0512
4	B	.0535
5	C	.0540
6	E	.0555
7	D	.0555
8	G	.0571
9	A	.0590

MONEY VALUE OF THE OILS TESTED.

The question that the operating engineer frequently asks himself is whether a proposed change of cylinder oils would be profitable, in other words, whether the cost of operation would thereby be reduced and to what extent this change of oils will affect the operating expenses.

At present, in the absence of reliable information on the lubricating values of cylinder oils, the method generally followed by operating engineers is, after comparing the market prices, to buy a certain brand of oil at the best rate obtainable, try it for a certain time on his engine and if it does not produce any ill effects after a reasonable time, to continue to use it, assuming it to be a good oil. But the question whether he has gained by this change or not, whether the operating expenses have been decreased or actually increased is not at all settled.

According to a paper on "The Theory of Finances of Lubrication" presented before the American Society of Mechanical Engineers by the late Professor Robert H. Thurston,* it is absolutely necessary to ascertain every item of expense affected by the proposed change.

These items of expense are classified by Prof. Thurston as follows:

(1) "The cost of power produced, only to be wasted by that of friction."

*A. S M. E. Vol. VI, 1885, pp. 437-

(2) "The expense incurred in wear and tear of the running parts, and in the replacement of parts destroyed, either by direct strains, or by gradual tear due to such exceptional resistances as are the effect of excessive friction."

(3) "The casual, indirect and often unperceived yet none the less serious losses throughout the system which are not included in the above."

(4) "The cost of the lubricating material applied for the purpose of ameliorating these losses."

The first item depends largely upon the cost and character of the fuel, type and size of the engine, the locality where the plant is situated, interest on the capital invested, depreciation, wages and insurance. The actual cost of producing one horse power per year may be as low as $30.00 and as high as $120.00 and in the following pages $80.00 was assumed as a fair estimate of the cost of production per horse power per annum.

The second and third items of expense cannot be estimated in dollars and cents with any degree of accuracy as they depend upon variable and generally unforeseen circumstances. As a rule these two items are included in the first item of expense as depreciation, and as a consequence their value, whatever it might be, is included in our assumed $80.00 per horse power per year.

If a proposed change in cylinder oil is desirable from the standpoint of economy, the money values of the oils should be determined by not only comparing the quantities and the cost of these quantities of oils used for a specified time, but also the other expenses incurred by using one oil instead of another.

In view of these briefly discussed considerations, the oils tested have been compared as to their money value assuming them to be used on a 70 horse power engine, and the results are given below:

Size of engine..............70 H. P............13 x 13

Cylinder circumference .... $\pi \times 13 = 40.82$ in.

Ring diameter .... 13.25 in.

Ring circumference .... $\pi \times 13.25 = 41.65$ in.

Spring tension 3 pounds per inch circumference.

Tension per ring ....$3 \times 41.65 = 124.95$ pounds

Tension for the 3 rings..............................373.85 pounds

Weight of piston ....110.00 pounds

Weight of piston rod .... 18.00 pounds

Total normal pressure ....510.85 pounds

Speed of engine ....275 revolutions per minute

Piston speed .... $\dfrac{275 \times 2 \times 13}{12} = 596$ feet per minute

Steam pressure 100 pounds per sq. in. gauge.
Horse power loss in the cylinder due to friction:

$$\text{H. P.} = \frac{510.85 \times 596}{33000} \times \text{friction cofficient}$$

H. P. loss in the cylinder = 9.23 x friction coefficient.

Quantity of oil in gallons per year of 360 days = 136.86 x s x d
where s = size of the oil drop in cubic centimeters.
d = drops of oil admitted into the cylinder per minute.
hence s x d = volume of oil in c c. admitted into the cylinder per minute.

TABLE 12.

Rate of Feed = .60 c c. per minute.—Steam pressure = 100 pounds per sq. inch.

Oil	Gallons per year	Cost of Oil per Gal., cents	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
H	82	45	$36.90	.378	$29.40	$66.30
I	82	38	31.16	.438	35.00	66.16
F	82	48	39.36	.473	37.80	77.16
D	82	45	36.90	.512	41.00	77.90
C	82	59.5	48.79	.498	39.90	88.69
B	82	60	49.20	.494	39.50	88.70
E	82	60	49.20	.512	41.00	90.20
A	82	60	49.20	.545	43.50	92.70
G	82	65	53.30	.527	42.20	95.50

TABLE 13.

Rate of Feed = 2 drops per minute—Steam Pressure = 100 pounds per sq. inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	19.15	$ 7.75	.523	$42.00	$49.75
H	30.10	15.18	.469	37.50	52.68
F	39.96	18.85	.602	48.20	67.05
D	52.00	23.40	.550	44.00	67.40
G	37.90	24.60	.567	45.35	69.95
B	65.60	39.40	.514	41.20	80.60
C	57.50	34.20	.582	46.50	80.70
E	43.80	26.30	.544	43.50	89.80
A	82.00	49.20	.550	44.00	93.20

TABLE 14.

Rate of Feed = 3 drops per minute.—Steam pressure = 100 pounds per square inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	29.80	$11.52	.487	$39.00	$50.52
H	48.80	22.98	.405	32.40	55.38
F	61.00	28.80	.494	39.50	68.30
D	72.40	32.60	.516	41.30	73.90
E	62.50	37.50	.525	42.00	79.50
G	57.00	37.00	.544	43.50	80.50
C	86.80	51.64	.498	39.90	91.50
B	100.00	60.00	.484	38.90	98.90
A	123.00	73.75	.485	38.90	112.65

TABLE 15.

Rate of Feed = 6 drops per minute.—Steam pressure = 100 pounds per square inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	61.60	$33.40	.446	$35.60	$69.00
H	98.50	43.50	.373	29.80	73.30
F	123.00	59.00	.470	37.60	96.60
D	157.40	70.80	.452	35.90	106.70
G	116.20	75.60	.516	41.30	116.90
E	134.00	80.50	.488	39.10	119.60
C	174.00	103.50	.446	35.60	139.10
B	192.80	115.10	.462	36.90	152.00
A	249.00	149.00	.456	36.50	185.50

From the above tables, it is readily seen that from whatever standpoint we consider the oils, either on the basis of equal volumes of oil or equal rates in drops per minute, oils I and H rank higher than the other oils tested. These oils have in their favor, besides a low cost also a low friction coefficient and also a small drop as compared with the other oils, which when the comparison is made on the basis of equal rates of feed in drops per minute, is a deciding factor in their favor.

But besides the cost of the oil and the cost of the power loss due to friction, or a combination of the two, there is the actual behaviour of the oil in the engine which must be given some consideration. Thus, the oil may get gummy, or it may not distribute well over the surfaces to be lubricated, or it may contain a comparatively large

amount of free acid or animal and vegetable fats, which to be sure reduce friction, but under the action of the high temperature in the cylinder will give off free acid that will attack the cylinder and in time corrode it.

Referring to table 4 we notice that oil H has the largest saponification number in comparison with the other oils, indicating that it is more apt to become gummy in the cylinder; it has also the largest per cent of animal and vegetable fats, similarly indicating that it will give off more free acid to corrode the cylinder.

As to oil I, we find that it has the largest free acid value (per cent oleic acid), besides having too small a drop, which in this instance may be considered a disadvantage, for on the basis of the same volume admitted into the cylinder, this oil will have to be fed at a pretty high rate, as compared with the other oils, and on the basis of equal rates of feed, the film of oil may not be sufficiently thick, especially as the viscosity of the oil decreases at higher temperature, and though the friction is decreased, it is decreased at the expense of the more rapid wear of the rubbing surfaces.

Oil F is the third in rank on the basis of cost. It has a low free acid value also a lower per cent animal and vegetable fat, which gives it a decided advantage over oils I and H.

Oil D does not differ very much from oil F, especially when the comparison is made on the basis of equal volumes and equal rates of two drops per minute. It is true that with two drops per minute, the necessary quantity of oil D is quite a good deal larger than the corresponding quantity of oil F on account of the difference in the size of the drops, but the friction coefficient of oil D is correspondingly smaller, resulting in a smaller amunt of power loss. Similarly, oil D contains a larger amount of free acid compared with oil F, but F has a larger per cent of animal and vegetable fats. All things considered then, there is not apparently much choice between these two oils for the rates of feed mentioned.

The other oils tested, although they have low acid values and low percent of animal and vegetable fats to their advantage, have correspondingly larger friction coefficients resulting in larger power loss, besides the higher cost and large size drops with increase in quantity for equal rates of feed, which is decidedly against them.

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The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and two research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

STUDY OF ARTESIAN WATER IN MISSOURI

INTRODUCTION

An artesian well may be defined as a vertical well in which the water rises near to or above the surface.

It is the purpose of this bulletin to outline the general artesian conditions in Missouri. Technical terms have been omitted and the facts studied have been stated as clearly as possible so that every one may get the fundamental points. Anyone wishing to study artesian waters more fully will find the best authorities listed in the bibliography.

In the investigation of the artesian water conditions of Missouri the county was made the areal unit and about thirty counties were visited and studied. Data from the remaining counties was obtained from officials of the principal towns, well drillers and private individuals interested in the work. Owing to the limited amount of time only a few days could be given to each county studied; and unfortunately the field work had to be done largely during the spring when the weather conditions were unfavorable for geological work. However, the operation of the deep wells was readily studied, and especial effort was made to visit the operating wells in several counties. Data as to depth, diameter, amount of water pumped, and approximate economical conditions were best obtained from the engineers in charge of the operation. Material both published and unpublished on Missouri conditions has been used freely.

The line of demarcation between artesian waters and surface waters is not every where exact, and is difficult to determine in some localities. The artesian waters of Missouri rise from a few principal formations of early Paleozoic age. Since the water conditions of these formations are fairly uniform over areas underlain by the water bearing strata, it is obvious that these waters are the most important and should be investigated first. Surface waters, owing to the variable factors of each locality, demand detailed study and consequently have been left for future work. Artesian waters become surface waters where the water bearing formations outcrop, but fortunately these areas are not extensive so that over the greater part of Missouri artesian waters are generally distinct from the surface waters.

Scientific investigation of deep wells has been greatly needed in Missouri. Although Dr. E. M. Shepard's work on Missouri under-

ground waters has been put before the people, city councils considering municipal water supplies still continue to visit and study neighboring communities having deep wells. The information thus obtained may in some cases prove valuable but at all times is indefinite and frequently misleading. The sources for efficient town or corporation supplies lie far below those of common wells and unless the local driller is familiar with the exact conditions, only approximate estimates can be furnished the prospector. Scientific knowledge of both general and local conditions makes it possible to offer new suggestions as to better sources of water and better methods of utilization.

The object of this investigation is to furnish the communities underlain by the principal water bearing formations some more or less exact data as to possible deep wells, that is, to show at what depths water may be reached, how high it will rise in the well, through what formations the drill must pass, what compounds the water is liable to contain, amount of discharge from the ordinary well, and the general economical conditions as compared with other sources.

Artesian water conditions are closely related to the geological structure of the locality. They vary according to altitude of the well site, the dip, texture and depth below the surface of the water bearing rock, and the distance from the outcrop of the same. Consequently the study of the geological conditions is of primary importance. Investigation of the outcrops of the water bearing rocks gives excellent information concerning their thickness and character and the relation of the overlying and underlying beds. The general dip may offer some idea of the depth at which such rocks may be struck in another locality. However, over an area as large as Missouri, formations dipping below the surface may be expected to become thicker or thinner and often pinch out and are replaced by different formations. The composition and texture of the formation is likely to change materially so that neighboring localities may obtain different waters from the same stratum. Local warpings not shown at the surface have a decided effect upon the water conditions and otherwise work against the general geologic evidence at the surface.

For these reasons the investigation of the deep water bearing formations must not be based on the surface geology alone, but also upon the data from the deep drill holes. Drillers' logs and sample cuttings are the source of this information. From these data attempts are made to correlate the strata penetrated, by knowing the surface conditions, the distance to the outcrops of the water horizons and the general dip of the same. By connecting well sections of different localities cross-sections may be made showing

the relations of the various formations across the state. Examples of these are shown in the accompanying plates.

The geologic evidence of deep underlying strata must come from records and samples of the drillings collected when the well is being drilled. In most cases these are not definite and have many possibilities of error. The driller often is careless in his record, sometimes failing to observe the important changes in the character of the beds penetrated, either because they are not easily recognized or perhaps have no direct effect on the water level in the well. Again the material of higher levels is constantly falling into the hole as it is drilled. The cuttings often show a great range of foreign material for beds at a certain depth. For example coal or shaly particles often are brought up with cuttings from crystalline limestone of the underlying rock known to be free from coal. Moreover a caving sand of a higher stratum may impregnate the magnesian limestone cuttings in a lower formation. Drilling data are liable to be the observation of persons not familiar with the character of cuttings and consequently questionable. The investigator can only take information of this kind and give it its proportionate weight and base his correlation of strata accordingly. In some cases corporations or individuals have realized the scientific importance of these records and have kept a complete list of the well cuttings. In most cases, unfortunately, no records have been saved or such incomplete ones that they are practically worthless. With such limited information for scientific research only approximations can be reached in this report. It will take careful observation and study for many years to make a thoroughly reliable report possible.

The most valuable record, geologically, of a deep well is a complete list of samples or cuttings obtained on the ground at the time of the drilling. These when carefully labeled with the depth from the surface at which they were obtained furnish an authentic succession of the various formations. Drillers are very apt to make mistakes in labeling or gathering samples after a considerable amount of cuttings have been obtained. Often several hundred feet of limestone are mistaken for the same formation and consequently it is necessary that samples should be taken every few feet. Also samples from every noticeable change should be taken. Professor W. H. Norton of the Iowa Geological Survey gives the following directions* for taking samples:

"For all scientific purposes samples should be taken directly from the sand pump at every five or ten feet, at the end of a cleaning out, and at every change of stratum. They should be placed unwashed, in wide-mouthed bottles or glass jars (one to four ounce bottles are large enough) and plainly and accurately labeled in India ink with the names of the town or other

*Iowa Geological Survey. Vol. 21. p. 87.

location, and of the owner, the date, and the depth from which each was taken."

In working over the cuttings for this report all were examined with a hand lens and some were studied under the microscope in order to identify more specific characteristics. Limestones were tested with cold hydrochloric acid and in cases where there was free effervescense it was assumed that the limestone was nearly pure unless chert or other foreign material could be determined with the lens. Slow effervescence when materially aided by heating was taken to designate magnesian carbonate. It was not considered necessary to determine the relative amounts of the different compounds or ingredients.

Even when the well cuttings are carefully saved there is still a possibility of error in completely correlating the various strata. In most cases too few samples are taken for a complete geological succession. Thin strata are often passed through unnoticed. The slush bucket may not carry up the cuttings of just one elevation alone but a mixture of all material that might have fallen from above during the last drilling.

After a set of well cuttings have been individually worked out, the correlation of strata with that of neighboring regions follows. One of the best means to determine the age of any rock is by the fossils it contains. However, in well cuttings the rock is usually crushed so badly that no recognizable fossils remain. The smaller fossils have some chance of escape but none were used as a means of correlation in this work.

Similarity of the rock is the most important method of connecting like strata. That is, correlating beds of like composition, structure, hardness, color, etc. For instance, the coal and shale beds in the coal measures do not correspond with the white crystalline limestones of the Mississippian, and are readily differentiated from them. These white cherty limestones likewise differ from the thin shaly limestones and sandstones of the Devonian. The Joachim formation, which is found in many Missouri well sections, is characteristically uniform, is marked by the absence of chert, and has the appearance of "cotton" rock. This is the first magnesian limestone encountered and consequently is an excellent horizon marker. The St. Peters sandstone is usually softer, coarser grained and less colored than the Roubidoux although the best method of distinction is by the relation to over-lying rock. If a sand is overlain by 100 or 150 feet of magnesian limestone it is most likely the Roubidoux sandstone, as the formation above (the Jefferson City) is the first thick magnesian limestone. The Jefferson City formation contains chert and sand and consequently is not easily mistaken for the

Joachim which is a thin, pure magnesian limestone. After the Ozarkian series is reached little use is made of lithological characteristics as the whole upper part of the series consists of sandy magnesian carbonates. Above the Ozarkian, however, this method of correlation estimated one which may outcrop some 50 miles or more away.

Another decided help to interpreting drillings is the known dip of the strata. Having the geologic map of Missouri, and the elevation of the outcrop and well site, the angle of dip completes the necessary data for finding the depth at which any bed may be found. Of course this computation assumes that local upwarpings and downwarpings are negligible and that the outcropping beds continue with the same thickness and dip. Sags and swells, thickenings and thinnings all are important in the exact location of underground strata, so that estimated depths may sometimes vary from 100 to 200 feet. However, in cases where the strata is comparatively uniform very close approximations may be made. Consequently when one formation is estimated to be reached at 750 feet below the surface at "A" and a similar formation is found at 800 feet, it is safe to assume that the formation occurring in the well at 800 feet is the same as the estimated one which may outcrop some 50 miles or more away.

The order of succession of strata is also an effective aid in working out well cuttings. The older formations occur at the bottom directly upon the granite floor and are succeeded by younger formations wherever they occur. In many cases formations occur only in limited areas of the state and consequently breaks in the succession according to locality are always looked for. For example, the Ordovician and Silurian rocks are almost entirely absent on the west side of the Ozarks and the limestones of the Ozarkian series occur directly below the Devonian shales and sands in the well sections.

The difficulties in drawing exact boundary lines between formations are noticeable. Often beds merge into others with the same composition and nearly the same structure so that it is hard to distinguish the difference in the field along the outcrop. Then again the variation of beds back underground from the outcrop may cause differences in the well section from that which might be expected. The meagre data, the uncertainty of conditions and the nature of the evidence acquired in so short a time necessarily impresses the possibilities of future change.

In response to the requests that have been made concerning forecasts of where and at what depths water may be found, a short part of this bulletin will be devoted to such approximations for different parts of the state. Under each of the county summaries something of this nature will be inserted in order that towns con-

sidering water supply from deep wells may have some idea of the existing conditions. In using these forecasts as a basis for estimation it must be understood that they are only approximate and just as nearly correct as a nine months' study will permit. However, enough is known of the deeper rock formations of Missouri to allow serious consideration of the deep well possibilities, and the forecasts put forward later may be used as approximate estimates.

The writer is greatly indebted to the courtesy of many people of Missouri and elsewhere. The commercial clubs of the state have afforded excellent opportunity for free correspondence concerning artesian conditions in different localities. Several railroads have generously furnished well logs and other data of value. Private corporations have offered assistance which has materially aided the work. Contractors and drillers have placed at our service the logs and cuttings of many wells, and in every case have been willing to save samples of wells being drilled. Several private citizens have taken a decided interest in this work and have furnished notes and in some cases private collections of well cuttings. For all these the writer is very thankful, and sincerely hopes that the bulletin may prove of service to them.

Especial acknowledgement is due Dr. E. B. Branson under whose direction the work was carried out. It was his investigation that first questioned the nomenclature of Missouri sandstones and by his suggestion the evidences for the mistake were brought out in this report. Professor T. J. Rodhouse largely furnished the information for the cost and adequacy of deep well supply.

CHAPTER I.

THE OCCURRENCE AND DESCRIPTION OF THE WATER BEARING FORMATIONS

The deep water supply areas of Missouri studied in this work may be divided into three provinces:

1. The area underlain by the St. Peters sandstone.
2. The area underlain by the Roubidoux formation.
3. The area underlain by the Gasconade formation.

The rocks in Missouri vary from the oldest known up to the most recent, though several periods are not represented. The St. Francis Mountains are largely made up of igneous rocks which represent the oldest or Pre-Cambrian series. These rocks are porphyries and granites and occur mainly in St. Francis, Iron and Madison counties. They form a nucleus around which the younger formations occur with the exception of the more recent formations of the

southeastern lowlands.

The section on page 11 gives a general idea of the sedimentary rocks that successively overlap the older formations. This section represents only approximate thicknesses and attempts to take in all the formations that occur generally to the north and west of the Ozarks. The thicknesses were taken from Buckley's* estimates, and from observations of a number of well sections. Many formations have not been shown because of their local nature, and others are shown thin because of a thinning tendency in the well section. This section is only to give the prospector and well driller some idea of the rocks that he will be most likely to penetrate. In using this section it is necessary first to determine the surface rock from a geologic map and then find the corresponding location of the surface on the section.

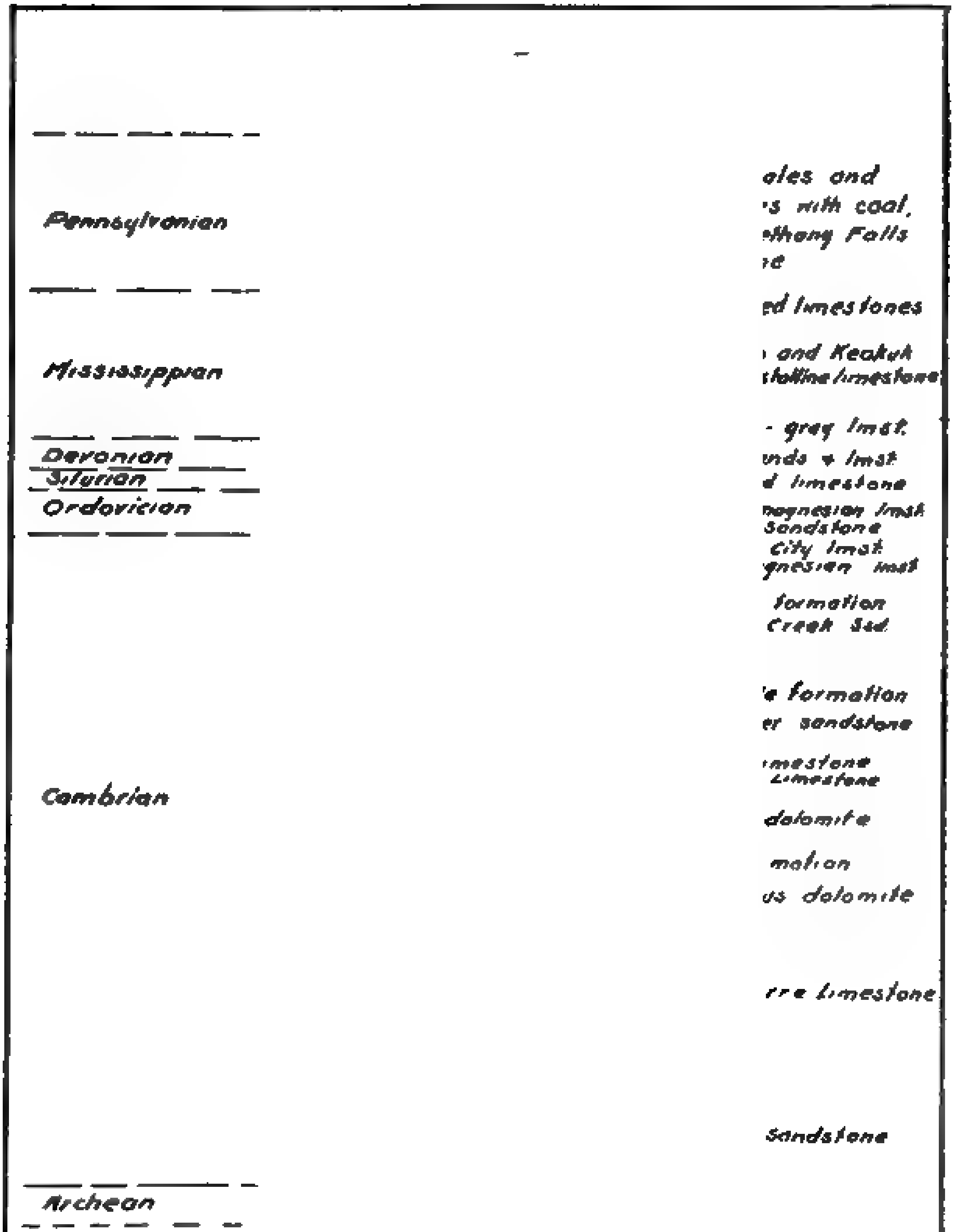
FIRST PROVINCE

The St. Peters sandstone underlies continuously the northeastern corner of Missouri. The southwestern boundary of this area seems to run from Crystal City through Pacific, approximately straight across to Moberly and from there north and northwest into Iowa. St Peters sandstone is found in many places in central Missouri and has often been supposed to occur in the southwestern part of the state but the well sections show that no wells out of the above named area furnish suitable water from the St. Peter sandstone. This sandstone may underlie the younger strata completely around the Ozarks, but not in such a manner as to supply deep wells.

In southern Boone and Callaway counties and also in Pettis County a sandstone similar to the St. Peters and in the proper place geologically, has been observed filling synclines or sags in the Jefferson City limestone. This indicates that the St. Peters sandstone was eroded from the central area before the younger rocks were formed. The Wabash Railroad well at Moberly is the farthest west of the wells obtaining water from the St. Peters sandstone. It was reached at 642 feet below the surface, and only 15 or 20 feet of sand is passed through in that vicinity.

There is a decided basin in the St. Louis region and a thickening of the formations over the St. Peters sandstone. In the Belcher Well at St. Louis there are some 1500 feet of sediment above the sandstone. This is peculiar to the St. Louis vicinity as the depth to the St. Peters sandstone varies from 200 to 1000 feet below the surface from the southern extremity of its area to the Iowa border respectively.

*Missouri Bureau of Geology and Mines, Vol. IX.



GENERAL SECTION

FOR NORTH-CENTRAL AND SOUTHWEST MISSOURI.

Scale 1" = 300.

The St. Peters is a loosely cemented sand, with the grains rather uniform in size and usually larger and more rounded than the grains of the older sandstones. The color is white except in places where particles of scattered iron rust have stained the stone brown or red. Stratification lines are absent and the ill-defined bedding planes are 10 feet or more apart. In thickness it varies from nothing to 200 feet. It outcrops at Crystal City, about 30 miles south of St. Louis, and also at Pacific about the same distance west. Smaller outcrops can be traced through Warren and Montgomery counties. In southern Callaway and Boone Counties this formation pinches out and the Joachim limestone rests directly upon the Jefferson City limestone.

The structure of the St. Peters sandstone is open and porous due to the well rounded grains of sand with little cementing material. The smoothness of the grains reduces friction to a minimum so that water may freely pass through the formation.

Some irregularities in northeastern Missouri, both in thickness of overlying strata and in the structure of the country rock, cause the study of the St. Peters to be complex. For example, a fold through Pike and Ralls counties raises the formation a hundred feet or more above the calculated elevation. Sufficient detailed information has not yet been obtained to follow out the exact effects of these folds and faults.

The water from this formation is comparatively pure and soft in the south and eastern parts of the district, due to the absence of soluble matter both in the grains and cement, but becomes impregnated with salt and sulphur in the north and west. Along the Mississippi River through Pike, Ralls and Lincoln counties many of the farm wells reach excellent water from this sandstone within a few hundred feet of the surface.

SECOND PROVINCE

The inner border of the Roubidoux province runs approximately through Gasconade, Cole, Morgan, Hickory, Polk, Webster and Stone counties. The area includes all southwestern Missouri as far north as Kansas City, and all north central Missouri south of Livingston, Linn and Randolph counties.

The Roubidoux outcrops in Morgan and Miller counties and swings around the Ozarks through the counties in south central Missouri. All the north central and southwestern parts of the state are underlain by it. It is one of the most important water horizons in the state and a large number of the deep wells in this area receive water from it.

The Roubidoux sand consists of fine grained, well rounded, iron stained quartz fragments. The sand beds are not continuous but occur in more or less lens shaped layers, being connected by porous cherty beds. The limestone is a porous magnesian lime and conducts the water just as well if not better than the sand. The average thickness of the Roubidoux formation is about 100 or 125 feet.

In the Columbia wells the water comes both from the sand and the limestone. One of the city wells did not strike any appreciable sandstone, but after fifty feet more of limestone had been drilled through its flow was as large as that of other wells within a few hundred feet that encountered sand. In the Carpenter-Schaffer well at Joplin, the sand did not furnish enough water, but one hundred feet of limestone below the sand carried a sufficient supply.

The water from the Roubidoux formation varies according to the locality. In Columbia it is comparatively hard, free from contamination, and excellent for domestic purposes. It is not especially good for boilers but by cleaning them every two or three weeks the scale is kept well under control. The water at Fulton is almost the same, but contains a compound that forms a hard scale in the water pipes, especially where the water is heated. The Carthage and Webb City wells furnish excellent water for almost every use demanded though it is a little hard. Joplin wells seem to contain a magnesian compound which is injurious to pipes and boilers. The water from the Clinton wells contains sulphur but no trouble is noticed commercially on that account. The Nevada Water Co. is bothered with the scale that forms in the meters; practically only one style of meter can be used, and repairs are necessarily frequent.

The Roubidoux elevation varies within its stated area of supply from 500 or 600 feet above sea level to 400 or 500 feet below sea level. This makes it possible to reach the formation from 200 to 500 feet from the surface along the border next to the Ozarks, and varying from there proportionally to 1000 or 1400 feet from the surface on the western and northern limits. No dry wells have been reported in the known Roubidoux area, and the wells have so nearly the same characteristics that it is safe to assume that the Roubidoux is continuous under the stated province and is a sure water horizon.

THIRD PROVINCE

The inner boundary of the area underlain by the Gasconade formation extends approximately from Washington, Crawford and Phelps counties on the north, south through Texas and Shannon counties to the southern border of the state. The outer border extends up to and overlaps the inner border of the Roubidoux area.

This does not indicate that wells may not obtain a sufficient supply of water from the Gasconade formation outside this area, but that the wells outside generally obtain their water from one of the formations nearer the surface. Often a well is drilled through the Roubidoux rock to obtain reinforcement from the Gasconade.

The water in this formation percolates through broken cherty beds and sandstone members. The lower sandstones of the Ozarkian formations are characteristically variable, wedging in and pinching out, but the porous limestone and broken cherts seem to be excellent water conductors. The Gunter sandstone is a continuous member and is important in the transportation of water. The water is similar to that of the Roubidoux as the two formations are closely related. The city supplies for the deep wells at Rolla, Lebanon and a number of smaller places are from this formation.

A number of wells in the state obtain water from local lenses of sandstone throughout various formations, but no definite work has been done with these since they did not belong to one of the three main divisions studied.

CHAPTER II.

CONDITIONS IN THE NORTHEASTERN DISTRICT

The northeastern district includes the area north of the Missouri River and east of Adair, Macon, and Randolph counties. The artesian conditions are not favorable throughout the entire area, but are especially good in the counties bordering the Mississippi River. The St. Peters sandstone is supposed to underlie this region but varies so widely within the area that the meagre records do not form a complete chain of evidence. The rocks dip to the west and north, the St. Peters sandstone rising steadily from the Iowa border. The eastern tier of counties has the most favorable location for artesian water because of the lower altitude of the surface and the relative rise in elevation of the St. Peters sandstone underlying them. A number of flowing wells are reported from this part of the district; Canton and LaGrange in Lewis County; Hannibal, Nelsonville and Oakwood, in Marion County; Spalding in Ralls County, and Louisiana in Pike County.

The deep well water in this region is variable and many waters are highly impregnated with salt and sulphur. This is probably due to the distance the water has traveled underground, and to local variations in mineral composition of the rocks encountered.

In the western and northern part the water is usually so burdened with mineral matter as to make it rather unsuitable for domestic purposes, but generally in the eastern and southern parts the quality is satisfactory.

In the following paragraphs the conditions in a number of counties are described and well logs given. Unless definitely stated otherwise the reader may assume uniform conditions throughout the county.

ADAIR COUNTY

Some years ago a well was sunk at Kirksville for the purpose of obtaining a city supply. The depth of this well is 1290 feet; the principal water comes from about 1150 feet and stands within 240 feet of the surface. It is highly impregnated with iron and sulphur and probably comes from the St. Peters sandstone but as only an imperfect record* of the well was kept this cannot be determined with certainty.

AUDRAIN COUNTY

A number of wells have been drilled in central and eastern Audrain County, the depths averaging from 150 to 500 feet. Abund-

*U. S. Geological Survey Water Supply Paper No. 195, p. 55.

Wells in Audrain County.

Location	Owner	Contractor	Driller	Depth in Feet	Diam. in Inches	Depth to the Principal Water. Feet	Yield in Gallons per minute: Flow	Yield in Gallons per minute: Pumped	Elevation above Sea Level. feet: Water Level	Elevation above Sea Level. feet: Well Site	Remarks
5 1-2 miles N. E. of Clark	Geo. E. Ess	Johnston Bros.	Johnston Bros.	216	5 1-2	190				874	
3 miles S. of Laddonia	W. T. Hughlett		D. F. Palmer	150	4	100		2	740	790	
Mexico			W. E. Smith	480						800	
5 miles N. of Mexico	Earl Carter	W. E. Smith	W. E. Smith	410	5 5-8	400		5	730	810	
1 mile N. of Mexico	Jas. Johnston	W. E. Smith	W. E. Smith	227	5 5-8	190		2	750	800	
6 miles N. of Mexico	Jas. Johnston			136	4			5			
2 miles E. of Mexico	Lawder Estate		R. J. Lawder	320	8	265			670	820	
8 miles N. of Vandalia	O. L. Fuque	G. W. Calvert	W. D. McDonald	306	6	280			674	780	
Vandalia	J. K. Moore		W. D. McDonald	290		290			685	775	
Mexico	Mexico City			1025	6	880					City water supply
Vandalia	Vandalia City			685	8	685		35	680	770	City water supply

ance of hard water rises within 50 or 75 feet of the surface and this provides excellent farm supplies.

The Water Works Company of Mexico drilled a well 1050 feet deep and a record was kept by the late Prof. G. C. Broadhead. The well is no longer used for city supply.

Log of Waterworks Well at Mexico, Mo.

	Depth in feet	Character of Rock. Remarks.
Pennsylvanian	15-25	Limestone, fragments of gray quartz or gravel
	35	Limestone, soft, drab, earthy
	50	Limestone, darker and harder, with black shale
	52	Black shale
	58	Limestone, soft, light bluish gray
	65	Limestone, light bluish gray
	70	Shale, black bituminous
	95	Limestone, fine grained, hard, dark fragments, gray
	100	Limestone, fine grained, soft, light gray, with fragments of black shale
	120	Limestone, fine grained, soft, light gray, with fragments of black shale
	140	Limestone, fine grained, soft, light gray, no shale
	145	Coal, bituminous
Mississippian	160	Chert, hard, gray with yellowish coating on some fragments
	165	Chert, hard, gray hornstone, some white and opaque
	180	Chert, hard, gray hornstone, some white and opaque
	200	Chert, hard, gray hornstone, some white and opaque
	220	Limestone, gray, compact, mixed with considerable chert
	240	Limestone, gray, compact, mixed with considerable chert and some black shale
	260	Limestone, gray, compact, with considerable white opaque chert
	270	Limestone, gray, compact, with considerable white opaque chert
	285	Limestone, white crystaline
	300	Limestone, dark brown, compact
	315	Limestone, dark brown, compact, much chert
	340	Limestone, light gray, compact and much chert
	345	Limestone, dark gray, compact, earthy
	360	Limestone, dark gray, compact, earthy
	380	Limestone, dark gray, compact, earthy
	400	Limestone, dark gray, compact, earthy.
	425	Limestone, dark gray, compact, earthy, considerable chert
	440	Limestone, crushed to white powder, effervesced freely
	450	Limestone, grayish crystaline
Probable Devonian, Silurian, and Ordovician	485	Sandstone, rounded white transparent quartz, some limestone and chert
	515	Sandstone, rounded white, transparent quartz, some limestone and chert
	530	Sandstone, rounded white transparent quartz, some limestone and chert.
	565	Limestone, light gray, soft earthy
	600	Limestone, light gray, soft, considerable green shale
	630	Limestone, light gray, soft, less shale
	670	Sandstone, white quartz, some white chert, gray limestone and green shale
	680	Limestone, gray, compact, earthy, some green shale

Log of Waterworks Well at Mexico., Mo.—Continued.

	Dept in feet	Character of Rock. Remarks.
	705	Chert, white (iron stained) few grains of quartz sand
	720	Limestone, gray, compact, earthy, some green shale and chert
	800	Limestone, gray, compact, earthy, some green shale and chert
Probable Cambrian	820	Limestone, gray, compact, earthy, some green shale and chert
	840	Limestone, gray, compact, earthy, some green shale and chert
	860	Chert, some limestone and green shale
	870	Limestone in soft yellow-white powder
	880	Sandstone, white quartz considerable limestone
	970	Limestone, soft, gray
	1025	Limestone, in powder, soft white

CLARK COUNTY

There are two wells at Kahoka; one owned by the city, and the other by the Clark County Canning Company, Kahoka. The city well was drilled in 1901-2. It is 509 feet deep, the water rises within 90 feet of the surface, and the supply is wholesome and sufficient for the town of 2500 people.

The Canning Company's well is 360 feet deep and the water stands 72 feet below the surface. Several veins of water were struck in this well, and the supply seems to be of excellent quality.

The Santa Fe Railroad Company drilled a well at Wyaconda in 1911. It is 633 feet deep, but on account of an unfortunate experience with deep wells at Baring, Missouri it was thought unadvisable to drill deeper. The log on page 20 was obtained from the Railroad Company:

KNOX COUNTY

The Santa Fe Railroad put down a test well in 1902 at Baring to the depth of 894 feet. This well furnished salt water only. During the years 1911-12, the company made a thorough test, drilling 2125 feet. Water was obtained at several horizons, but was so impregnated with solid matter that it was too expensive to treat for boiler water. The St. Peters sandstone was struck at 944 feet in the deep well and 865 feet below the surface in the shallow one. A copy of the log of this well was furnished by the railroad company.

A well 523 feet deep was drilled 8 miles southwest of Knox City on a farm owned by Jack Rennen. The diameter of the hole is 4½

Log of Wyaconda Well.

Drilled in 1911; Walter Price, driller.

	Depth in feet	Character of Rock. Remarks.
Pennsylvanian	0 to 3	Soil
	3 to 65	Yellow clay
	65 to 105	Blue clay
	105 to 140	Yellow clay
	140 to 209	Blue clay
	209 to 218	Sand, a little water, 1½ bailer full after 40 minutes.
Mississippian	218 to 235	Blue clay
	235 to 260	Limestone
	260 to 264	Blue clay
	264 to 290	Limestone
	290 to 295	Blue clay
	295 to 341	Limestone
	341 to 390	Blue clay
	390 to 484	Shale, a little water between 460 and 484 feet.
	484 to 502	Sand rock
	502 to 518	Water bearing sand, 16 gals. a minute.
	518 to 598	Limestone
	598 to 603	Slate
	603 to 608	Shale
	608 to 628	Limestone
Devonian	628 to 633	Blue clay
	633	Plugged hole and abandoned well
		Well cased, 13 inch for 101 feet, 10 inch for 239 feet.

Log of Baring Well.

Drilled in 1911-12. First 1500 feet, Harris, driller; 1500 feet to 2125 feet, Shaffer, driller.

	Depth in feet	Character of Rock. Remarks.
Pleistocene	0 to 100	808 ft. above sea level. Blue clay
Mississippian	100 to 175	St. Louis limestone and Osage Group. Seap of water below 115 ft. 13" shoe at 115 feet.
	175 to 275	Chert, white limestone chalcedonic and crystalline silica.
	275 to 280	Green gray shale with irregular grains of crystalline quartz, calcareous.
	280 to 345	White limestone
	345 to 360	Very coarse sandstone
	360 to 375	Chert, fine sand of particles of cryptocrystalline silica, water bearing. Tested well, 65 gallons a minute.
	375 to 410	Light yellow marl, rapid effervescence.
	410 to 465	Light drab limestone
	465 to 498	Kinderhook shale; 10" shoe made a dry hole 310 feet above sea level.
Devonian	498 to 510	....
	510 to 745	Gray limestone, rapid effervescence, fossiliferous with joints of crinoid stems and fragments of shells of brachipods.

Log of Baring Well—Continued.

inches, the water rises within 125 feet of the surface, and about 15 gallons per minute are pumped. The supply is salty.

LEWIS COUNTY

On the grounds of the Christian University at Canton, the city drilled a well for fire protection. It is 900 feet deep; 6 inch casing to 100 feet; flow 72 gallons per minute. A strong flow of water was struck in the St. Peters sandstone at 870 feet below the surface. The water is used for nearly all domestic purposes but it has a slight sulphur odor, and possesses mild laxative qualities. The Aqua Vitae Mineral Springs Company sub-leased the right to ship water for medicinal purposes.

At LaGrange there are three flowing wells. One was originally owned by the LaGrange Mineral Well Prospecting Company. Later the two oldest wells came under the same ownership, and their products sold as the "Wyaconda Water."

The depth of these wells is 800 and 850 feet but only imperfect records were kept of the drilling. The main flow of water was reached at about 800 feet in the St. Peters sandstone. The flow varies from 40 to 60 gallons per minute and is excellent water.

In June 1913 Mr. W. W. Heald finished an 850 foot well at LaGrange. Abundance of fresh water was reached at a depth of 200 feet, but flowing water began at the 800 foot level. The drilling was continued until a depth of 850 feet was reached. The diameter of the well is 6 inches, and the water flows from the mouth with a 40 pound pressure. The quality of the water seems similar to that of the previous wells at LaGrange. The following is a log determined from the samples obtained.

Log of LaGrange (1913) Well.

	Depth in feet	Character of Rock
Pleistocene	20	Clay and soil
Mississippian	93	Limestone and flint
	165	Shale and limestone
	185	Brown limestone
	210	Pink limestone
Probable Devonian	360	Shale and thin limestone
Silurian and Ordovician	518	Limestone
	520	Chert and limestone
	534	Limestone
	542	Limestone with sand bearing small lead cubes
	743	Chert with limestone
	850	Limestone and fine sand

LINCOLN COUNTY

A well owned by G. S. Brown at Ethlyn is 187 feet deep, 6 inches in diameter; principal source 185 feet and water rises within 52 feet of the surface.

Near Troy there is a well owned by N. Hanni which is 136 feet deep. This well flows about 1 gallon per minute. No logs were kept of these wells, but their water probably comes from the lower Mississippian or Devonian rocks.

MARION COUNTY

In Marion County there are a number of flowing and non-flowing wells. The principal source of supply is from the St. Peters sandstone which is reached from 600 to 800 feet below the surface. The water although containing salt and sulphur is generally used for domestic purposes.

The following log of the Vernet well at Hannibal was obtained from Mr. R. Hawkins of Chillicothe:

Log of Vernet Well, Hannibal, Mo.

	Depth in feet	Thickness of Strata feet	Character of Rock. Remarks.
Pleistocene	0 to 41	41	Soil and clay
Mississippian	41 to 195	154	Shales and limestones
	195 to 300	105	Blue limestone
Devonian	300 to 333	33	Black slate
	333 to 347	14	Salt water sand
Silurian and Ordovician	347 to 601	254	Limestone
	601 to 697	96	Mineral water sand; St. Peters; water rose within 40 feet of the surface.
Cambrian	697 to 950	253	Limestone, hard; fine sand at intervals; water rose to 20 feet from surface.
	950 to 1000	50	Hard limestone
	1000 to 1005	5	Soft, white sand (Roubidoux)
	1005 to 1055	50	Limestone
	1055 to 1205	150	Limestone and interstratified sand
	1205 to 1225	20	Sand
	1225 to 1275	50	Magnesian limestone
	1275 to 1285	10	Hard, white sand; water within four feet of surface.
	1285 to 1389	104	Magnesian limestone; water flowing.
	1389 to 1435	46	Unaccounted for

MONROE COUNTY

The Monroe County Poor Farm has a deep well 2½ miles southeast of Paris. It is 5½ inches in diameter and the depth is 430 feet. The water rises to within 90 feet of the surface. The principal water comes from 420 feet below the surface and is probably from the St. Peters sandstone.

Wells in Marion County, Missouri.

Location	Owner	Contractor	Driller	Depth in Feet	Diam. in Inches	Depth to Principal water. Feet.	Yield in gallons per minute		Elevation above sea level. Feet.		Remarks
							Flow	Pump	Water level	Well Site	
Hannibal	Mrs. Vernet			1485	6	1005			575	608	Salt water
Hannibal	Richard Stillwell Meat and Ice Co.			950	8	800	208		500	475	50 lbs. pressure, saline
3 miles S. of Nelsonville	C. H. Mohr		C. H. Mohr	720	4 1-2	685	1 1-4				
3 miles S. of Nelsonville	C. H. Mohr		C. H. Mohr	875	4 1-2	600	10				Water rises in pipe 12 ft. above surface
3 3-4 miles N. W. of Monroe City	W. R. Jackson		C. S. Jackson	700	6	.					Incomplete report
Palmyra				1688		700					Flowed

In the spring of 1913 Monroe County attempted to install a deep well for city supply, but the project was unsuccessful. A well was bored 2150 feet, and cased about 1600 feet. Only salt water was obtained from this well, although definite information about the water at various horizons was not saved. The salt water was struck about 500 feet below the surface in the probable St. Peters sandstone, and another flow which seemed fresh at first and later became salty, was encountered at 1000 or 1100 feet. This water might have proved fresh, had the salt water been properly cased off from above. The city was under considerable expense for the drilling, and consequently abandoned the proposition.

MONTGOMERY COUNTY

Numerous wells are known in Montgomery County, varying in depth from 100 to 250 feet. These wells furnish good water for stock and farm uses. No record of any has been kept.

PIKE COUNTY

At Louisiana, Missouri, the old "Thespian Spring" is famous as an artesian well. It is 1275 feet deep and 6 inches in diameter. The principal source of supply is about 600 feet below the surface in the St. Peters sandstone as stated by Dr. Shepard.* The water bubbles up with about an eight foot head, and is strongly charged with salt and sulphur. At present the water is not used extensively for drinking purposes.

RALLS COUNTY

The St. Peters sandstone is penetrated by most of the wells in Ralls County from 250 to 400 feet below the surface. The sandstone is reported to outcrop in the extreme eastern part of the county, and most of the wells are situated in the western and southwestern parts. The water obtained in some cases is soft while in others it contains sodium and magnesium salts.

RANDOLPH COUNTY

This county is about on the dividing line, between the St. Peters and Roubidoux provinces, being the westernmost county showing St. Peters sandstone. A number of wells have been drilled in the county, but records of only a few have been obtained. The Wabash Railroad drilled 642 feet at Moberly in 1901 and reached St. Peters sandstone at 629 feet from the surface. A good, comparatively soft water was obtained at this horizon.

*U. S. Geological Survey Water Supply Paper No. 195, p. 52.

Log of Wabash R. R. Co. Well, Moberly, Mo.

Drilled in 1901.

	Depth in feet	Thickness of strata feet	Character of Rock. Remarks.
Pleistocene	0 to 78	78	Drift
Pennsylvanian	78 to 84	6	White limestone
	84 to 88	4	Clay (caving)
	88 to 218	130	Sandstone, some water in top.
	218 to 236	18	Fire clay
Mississippian	236 to 281	45	Gray limestone
	281 to 291	10	Brown shale or slate
	291 to 298	7	Sand stone, a little water.
	298 to 310	12	Clay, caving
	310 to 335	25	Blue and white limestone
	335 to 340	5	Soapstone
	340 to 400	60	Dry, hard, sandstone.
	400 to 545	145	Blue limestone (hard and soft)
Devonian and Joachim	545 to 553	8	Dark brown shale
	553 to 556	3	Water sand
	556 to 568	12	Blue shale
	568 to 613	45	Trenton rock
	613 to 629	14	White, soft limestone.
St. Peters	629 to 642	15	Sandstone (St. Peters?)

The city water plant at Moberly pumps two eight inch wells. The depths of these are 500 and 510 feet respectively. About 150,000 to 200,000 gallons can be pumped from each well per day at a maximum, but both cannot be run on full load at the same time. The water obtained is very satisfactory for domestic purposes.

Some years ago a 2000 foot well was drilled at Moberly, and excellent water obtained at 632 feet. At 870 feet the water became salt and from there on was impregnated with salt and sulphur. The record of this well is in U. S. Geological Survey Water Supply Paper, No. 195, p. 102.

In the record Dr. Shepard has correllated the sand at 1105 feet as the St. Peters sandstone. In this work that sand has been called the Roubidoux and the sandstone at 632 feet called the St. Peters. The reasons for this change are as follows:—In Dr. Shepard's correllation he has shown 95 feet of Niagarian, 234 feet of the Hudson group, and 131 feet of Trenton rock. These aggregate 450 feet of materials above the 1100 foot sandstone that do not outcrop anywhere south along the Missouri River in Howard, Boone and Callaway Counties. As stated in the chapter on conditions of the North-eastern Province, the St. Peters sandstone pinches out in southern Callaway and Boone Counties and is found only in isolated patches, occupying synclines directly below the Joachim, and never more than 100 feet below the Mississippian. No Trenton, Niagarian or Hudson rocks are known to outcrop in Missouri west of a thin pinching section in the northeastern part of Callaway County. Moreover a deep well at Centralia strikes the Roubidoux sandstone at 1085 feet below the surface. A deep well at Marceline strikes a similar sandstone at 1104 feet. These two localities are about equally distant on either side of Moberly. In the Centralia well a water bearing sandstone was encountered at 534 feet and this has been supposed to be a thin edge of the St. Peters as it is not shown in the Columbia wells farther south.

A number of wells in Randolph County obtain a good supply of water at about 600 feet, evidently from the so-called St. Peters horizon. The water rises to within about 75 feet of the surface and is of excellent quality but the Robidoux water 400 feet below seems to be highly mineralized (due to local underground conditions) and can not be used for domestic purposes.

SCOTLAND COUNTY

Near Rutledge there have been several wells drilled for farm purposes. These vary in depth from 300 to 500 feet but do not strike the St. Peters sandstone. The water is hard and probably comes from the lower Mississippian or upper Devonian rocks.

WARREN COUNTY

At Warrenton there is a well which strikes the St. Peters sandstone at 360 feet below the surface. It is 400 feet deep and is 6 inches in diameter. There are several wells at Wright City varying from 100 to 250 feet deep. These furnish a good supply of hard water but it is not thought to come from the St. Peters sandstone. It is safe to assume that a good quantity of water may be expected throughout the northern half of Warren and Montgomery counties within 400 feet of the surface.

ST. LOUIS AND ST. LOUIS COUNTY

The rocks in the St. Louis region lie in a peculiar trough. The surface formation is the Upper Coal Measures, and sections show a great increase in thickness of underlying strata. At the corner of Main and O'Fallon streets, St. Louis, a well known as the Belcher well was finished in 1854. The depth of this well is 2199 feet; elevation 420 feet; and it flows about 75 gallons per minute. A detailed description of this historic well may be found in "Transactions St. Louis Academy of Science." Vol. I, 1860, pp. 82 to 86.

In 1869 a deep well was completed at the St. Louis Insane Asylum. The log of this well was furnished by the late Prof. G. C. Broadhead, who published the same in the Transactions of the St. Louis Academy of Science, Vol. 3, No. 2, 1878, p. 216. The elevation of the well site is about 600 feet; the St. Peters sandstone was struck at 1452 feet and furnished an abundant supply of sulphurous water.

A number of wells have been drilled in St. Louis County varying in depth from 100 to 1500 feet. In all drillings to 1400 or 1500 feet a rather salty water is obtained from the St. Peters sandstone. Shallower wells furnish water, but not in great quantity. The water from the deeper wells rises to within 100 feet of the surface and a few wells are flowing.

Log of Insane Asylum Well, St. Louis.—Broadhead.

	Depth, in feet	Thickness of strata feet	Character of Rock. Remarks.
	0 to 40	40	Clay
	40 to 44	4	Limestone, not in place.
	44 to 49	5	Red clay
	49 to 57	8	Limestone
	57 to 61	4	Red clay
	61 to 66	5	Coal
	66 to 68	2	Fire clay
Pennsylvanian	68 to 71	3	Light colored limestone (begin boring)
	71 to 80	9	Blue and drab clay, slightly calcareous.
	80 to 86	6	Cherty limestone
	86 to 107	21	Dark and bluish grey shales, slightly calcareous
	107 to 111	4	Cherty limestone
	111 to 112	1	Coal
	112 to 120	8	Light blue clay
	120 to 259	139	Hard cherty limestone, blue, drab and grey, upper part fine and lower course ground.
	259 to 262	3	Blue shales
	262 to 438	176	Drab and grey limestone
	438 to 500	62	Dark drab limestone
	500 to 536	36	White limestone and shale (record)
	536 to 628	92	Hard, blue cherty limestone.
	628	....	Very hard chert
Mississippian	628 to 763	75	Coarse, bluish grey limestone.
	703 to 709	6	Sandstone, very fine grained.
	709 to 790	79	Light grey or drab limestone, cherty.
	790 to 800	10	Red limestone
	800 to 835	35	Light drab and grey limestone, some chert.
	835 to 840	5	Argillaceous limestone
	840 to 883	43	Limestone with some chert, light grey.
	883 to 950	67	Light blue or blue clay
	950 to 966	16	Dark clay
	966 to 1022	56	Blue clay, alternating with thin limestone layers.
	1022 to 1216	194	Blue and drab limestone, probably some magnesian layers at 1139 feet.
Devonian	1216	....	Colored magnesian limestone
Silurian and	1216 to 1225	9	Light blue cherty limestone, salt water at 1220 feet.
Ordovician	1225 to 1252	27	Light colored limestone
	1252 to 1304	52	Dark limestone
	1304 to 1353	49	Light drab, cherty limestone.
	1353 to 1370	17	Yellowish grey limestone
	1370 to 1448	78	Dark colored limestone
	1448 to 1452	4	Light colored limestone
	1452 to 1583	31	White rounded grains quartz sand containing sulphurous water; (St. Peters)
	1583 to 1646	63	Buff, brown and drab cherty limestone.
	1646 to 1713	67	Buff, brown, magnesian limestone.
	1713 to 2102	389	Buff, drab, cherty magnesian limestone.
Cambrian	2102 to 2184	82	Hard and mostly pure sandstone, some limestone and chert, buff, brown, reddish, grey; (Roubidoux)
	2184 to 2671	487	Limestone and chert, beds of chert about one half.

Log of Insane Asylum Well, St. Louis—Continued.

	Depth in feet	Thickness of strata feet.	Character of Rock. Remarks.
	2671 to 2735	64	Limestone, no chert, sand.
	2735 to 2843	108	Limestone and sand
	2843 to 2880	37	Sandstone, some limestone.
	2880 to 3022	142	Limestone, mainly free from chert and sand.
	3022 to 3120	98	Sandstone, upper part cherty, middle blue, lower reddish grey
	3120 to 3133	13	Dark magnesian slate.
Cambrian	3133 to 3504	371	Yellowish drab or grey magnesian limestone, hard, little sand; lower part thin, bedded with sand.
	3504 to 3545	41	Thin bedded hard sandstone, olive grey color
	3545 to 3558	13	Sand and limestone.
	3558 to 3843	285	Brown sandstone in upper part, lower 40 ft. powdered granite.

CHAPTER III.

CONDITIONS IN THE CENTRAL AND SOUTHWESTERN DISTRICT

This province includes the area underlain by the Roubidoux sandstone. The artesian conditions vary uniformly throughout the district, and good results from deep wells are much more general in this area than in northeastern Missouri. The rocks dip mostly to the north in the central counties and to the west in the southwestern ones; the counties on the inner border having the most favorable location. Flowing wells are not common in the province, although the best conditions for flowing wells in the state are probably found at Clinton. Flowing wells are reported from Newton, McDonald and Saline counties.

The quantity of water is sufficient in all localities where it can be pumped economically. The quality varies with local conditions, sometimes being impregnated with salt and sulphur, but not generally so burdened with mineral matter as to be objectionable for domestic uses. In Howard, Saline, Lafayette, Chariton and Linn counties the Roubidoux formation furnishes a strong salt water. It is the general belief of the writer that fresh water can be obtained in these localities from the Gasconade sandstone 300 to 400 feet below the Roubidoux as was illustrated in one of the Higginsville wells but this can only be substantiated or disproved by actual experiment.

BOONE COUNTY

Boone County is underlain by the Roubidoux formation and a number of wells yield an excellent supply of water from this horizon. The sandstone may be reached at about 400 or 500 feet below the surface in the extreme southern part of the county and varying from there to 900 or 1000 feet along the northern boundary.

The following is a log of the University well which was very carefully kept and worked out. This may be taken as an average Boone County section.

Log of University of Missouri Well No. 2, Columbia, Mo.

The well is located 25 feet south of the Engineering Annex Building on the campus of the University. Surface elevation, 740 feet.

	Depth in feet	Thickness of Main formations in feet	Thickness of strata in feet	Character of Rock
	0 to 35	35	....	Mantle rock, part fill
Mississippian	35 to 200	165	....	Burlington limestone
	200 to 260	60	....	Chouteau limestone
Devonian	260 to 261	1	....	Sandstone
	261 to 301	40	....	Limestone

Log of University of Missouri Well No. 2, Columbia—Continued.

		Depth in feet	Thickness of main formations in feet	Thickness of strata in feet	Character of Rock	
Cambrian	Jefferson City	301 to 680	379	79	Limestone	Limestone (Magnesian and generally cherty)
				5	Sandy limestone	
				123	Limestone	
				2	Fine grained sandstone	
				10	Light colored calcareous shale	
				5	Dark shale	
				7	Limestone	
				8	Sandstone, fine to coarse grained.	
				30	Limestone	
				5	Sandstone, fine grained, white.	
				20	Limestone	
				2	Sandstone	
				11	Limestone	
				7	Sandstone	
				49	Limestone	
				1	Sandstone	
				15	Limestone	
	Roubidoux	680 to 770	90	12	Fine grained sandstone	(Bolin sandstone)
				23	Limestone	
				41	Sandstone, fine grained, well rounded.	
				3	Limestone	
				11	Sandstone to bottom of well	

CALLAWAY COUNTY

The conditions in Callaway County are similar to those of Boone County. Excellent water from the Roubidoux formation is obtained by a number of wells in Fulton and elsewhere. The depth of sandstone below the surface varies from about 400 to 900 feet from southern to northern extremities respectively. Logs of the Fulton wells are about the same as the Columbia well logs.

Wells in Boone County, Missouri.

Location	Owner	Contractor	Driller	Depth in Feet	Diameter in Inches	Depth of principal water	Yield in gallons per minute: Flow	Yield in gallons per minute: Pumped	Elevation above sea level: Water level	Elevation above sea level: Well Site	Remarks
Columbia	University	W. R. Nifong	W. R. Nifong	967	10-6	750-900			616	736	Steam pump
Columbia	University	O. G. Wilson		792	15 1-4-8	750-792		250	600	740	Electric motor-driven pump
Columbia	Christian College	W. R. Nifong	W. R. Nifong	676	5 5-8	525			630	750	
Columbia	Hetzler Bros' Ice Plant			617		500					
Columbia	Hetzler Bros' Ice Plant			640		500					
Columbia	Hamilton-Brown Shoe Co.			957	6 1-4	700-900		80	615	765	
Columbia	City of Columbia	P. L. Crossman		801	15-10	780		259			City water supply. Elec. motor driven pump
Columbia	City of Columbia	P. L. Crossman		848	15-10	780-814		259	603	795	City water supply. Electric motor driven pump
Centralia	City of Centralia	O. G. Wilson		1118	12-8	1085		200		885	City water supply
Centralia	City Development			1850	6 1-4	850-1000				885	Stopped, soft spot in slate demanded more casing
Columbia	City water works				10-6			150			City supply, air lift pumps
Columbia	City water works				10-6			150			City supply, air life pumps

Wells in Callaway County.

Location	Owner	Contractor	Driller	Depth in Feet	Diam. in Inches	Depth to principal water	Yield in gallons per minute: Flow	Yield in gallons per minute: Pumped	Elevation above sea level: Water level	Elevation above sea level: Well Site	Remarks
Fulton	City of Fulton	C. A. Wise	Jack Farro	1121	9	700-1000		250	670	820	Sandstone and limestone. City supply
Fulton	City of Fulton			800	8	800			670	820	City supply
Fulton	Deaf and Dumb School		Simmons	700	6			60	680	820	School supply
Fulton	State Hospital			1100	6	700-1000		72	670	820	Water very hard Use lime softener
Fulton	State Hospital			950	10	700-950		95	670	820	Water very hard Use lime softener
Fulton	State Hospital	Edwards, Diemer & Donner	W. M. Edwards	1000	12	700-100		350	670	820	Drilled fall of 1912
½ mile S. W. of McCredie	Crawford			115	7	115				860	Soft water
½ mile S. E. of McCredie	Harrison			130	7	130				850	Soft water
7½ mi. N. E. of Cedar City	George Carlton			1300							Water flows. Drilled for oil but none found
Cedar City	F. M. Pease & Co. Chicago	Chas. York	Chas. York	1282	10	800-1200				560	Stopped on account of excessive water pressure. Flows.

Wells in Boone County, Missouri.

Location	Owner	Contractor	Driller	Depth in Feet	Diameter in Inches	Depth of principal water	Yield in gallons per minute		Elevation above sea level		Remarks
							Flow	Pumped	Water level	Well Site	
Columbia	University	W. R. Nifong	W. R. Nifong	967	10-6	750-900			616	736	Steam pump
Columbia	University	O. G. Wilson		792	15 1-4-8	750-792		250	600	740	Electric motor-driven pump
Columbia	Christian College	W. R. Nifong	W. R. Nifong	676	5 5-8	525			630	750	
Columbia	Hetzler Bros' Ice Plant			617		500					
Columbia	Hetzler Bros' Ice Plant			640		500					
Columbia	Hamilton-Brown Shoe Co.			957	6 1-4	700-900		80	615	765	
Columbia	City of Columbia	P. L. Crossman		801	15-10	780		259			City water supply. Elec. motor driven pump
Columbia	City of Columbia	P. L. Crossman		848	15-10	780-814		259	608	795	City water supply. Electric motor driven pump
Centralia	City of Centralia	O. G. Wilson		1118	12-8	1085		200		885	City water supply
Centralia	City Development			1850	6 1-4	850-1000				885	Stopped, soft spot in slate demanded more casing
Columbia	City water works				10-6			150			City supply, air lift pumps
Columbia	City water works				10-6			150			City supply, air life pumps

Wells in Callaway County.

Location	Owner	Contractor	Driller	Depth in Feet	Diam. in Inches	Depth to principal water	Yield in gallons per minute		Elevation above sea level		Remarks
							Flow	Pumped	Water level	Well Site	
Fulton	City of Fulton	C. A. Wise	Jack Farro	1121	9	700-1000		250	670	820	Sandstone and limestone. City supply
Fulton	City of Fulton			800	8	800			670	820	City supply
Fulton	Deaf and Dumb School		Simmons	700	6			60	680	820	School supply
Fulton	State Hospital			1100	6	700-1000		72	670	820	Water very hard Use lime softener
Fulton	State Hospital			950	10	700-950		95	670	820	Water very hard Use lime softener
Fulton	State Hospital	Edwards, Diemer & Donner	W. M. Edwards	1000	12	700-100		850	670	820	Drilled fall of 1912
½ mile S. W. of McCredie	Crawford			115	7	115				860	Soft water
½ mile S. E. of McCredie	Harrison			130	7	130				850	Soft water
7½ mi. N. E. of Cedar City	George Carlton			1800							Water flows. Drilled for oil but none found
Cedar City	F. M. Pense & Co. Chicago	Chas. York	Chas. York	1282	10	800-1200				560	Stopped on account of excessive water pressure. Flows.

CALDWELL COUNTY

On the Robert Davis farm, 3 miles northwest of Braymer, the N. M. Murrey and Lecredopmut Co., drilled a well 1410 feet deep. The record of this well was carefully kept, although no report on the character of the water from the Roubidoux sandstone was obtained. Caldwell County is on the outer border of the Roubidoux province (that is, north or west of this county it would not be economical to drill to the Roubidoux sandstone for water). Good water seems to be furnished by wells ranging in depth from 150 to 300 feet, but below this depth the quality of the water is questionable. The following log of the Braymer well was furnished by Mr. R. Hawkins of Chillicothe,

Log of Braymer Oil Well, 3 Miles N. W. of Braymer, Mo.

N. M. Murrey and Lecredopmut Co.

	Depth in feet	Thickness of strata. feet	Character of Rock. Remarks.
Pleistocene	0 to 14	14	Clay
	14 to 19	5	Limestone
	19 to 20	1	Sandstone
	20 to 24½	4½	Limestone
	24½ to 34	9½	Sandstone
	34 to 42	8	Oil shale
	42 to 44	2	Soapstone
	44 to 56	12	Shale
	56 to 62	6	Limestone
	62 to 68	6	Slate and sand
	68 to 76	8	Oil sand
	76 to 81	5	Sand and slate
	81 to 87	6	Soapstone
	87 to 90	3	Sand and slate
	90 to 95	5	Soapstone
	95 to 99	4	Oil sand
	99 to 135	36	Soapstone
	135 to 143	8	Keel
	143 to 155	12	Soapstone
	155 to 171	16	Keel
Pennsylvanian	171 to 179	8	Limestone
	179 to 190	11	Soapstone
	190 to 193	3	Hard limestone
	193 to 198	5	(No record)
	198 to 210	12	Limestone
	210 to 228	18	Sandstone
	228 to 235	7	Sand
	235 to 237	2	Limestone
	237 to 242	5	Slate
	242 to 243	1	Soapstone
	243 to 244	1	Limestone
	244 to 246	2	Keel
	246 to 251	5	Limestone
	251 to 264	13	Soapstone
	264 to 266	2	Keel
	266 to 270	4	Soapstone
	270 to 274	4	Hard limestone
	274 to 301	27	Soft limestone
	301 to 311	10	Soapstone
	311 to 325	14	Shale
	325 to 330	5	Soapstone
	330 to 345	15	Limestone

Log of Braymer Oil Well—Continued.

	Depth in feet	Thickness of strata feet	Character of Rock. Remarks.
Pennsylvanian	345 to 350	5	Soapstone
	350 to 351	1	Hard flint
	351 to 353	2	Slate
	353 to 354	1	Hard flint
	354 to 375	21	Limestone
	375 to 377	2	Soapstone
	377 to 382	5	Sand shale
	382 to 383	1	Limestone
	383 to 394	11	Soapstone
	394 to 395	1	Limestone
	395 to 396	1	Coal
	396 to 399	3	Soapstone
	399 to 410	11	Dark clay
	410 to 420	10	Soft limestone
	420 to 431	11	Soapstone
	431 to 433	2	Limestone
	433 to 434	1	Coal
	434 to 437	3	Slate
	437 to 441	4	Limestone
	441 to 462	21	Shale
	462 to 470	8	Clay
	470 to 473	3	Limestone
	473 to 501	28	Dark shale
	501 to 507	6	Soft limestone
	507 to 517	10	Dark shale
	517 to 518	1	Flint
	518 to 524	6	Slate
	524 to 528	4	Iron shale
	528 to 534	6	Limestone
	534 to 543	9	Soapstone
	543 to 544	1	Limestone
	544 to 563	19	Soapstone
	563 to 569	6	Limestone
	569 to 599	30	Dark shale
	599 to 672	30	Saline sand
	632 to 634	2	Soapstone
	634 to 652	18	Sandstone
	652 to 660	8	Grayish dark clay
	660 to 664	4	Clay
Mississippian	664 to 666	2	Hard sandstone
	666 to 673	7	Hard sand
	673 to 767	94	Limestone
	767 to 770	3	Salt water
	770 to 797	27	Limestone
	797 to 798	1	Blue shale
	798 to 886	88	Limestone
Devonian and probable Ordovician	[illegible]6 to 916	30	Slate
	916 to 941	25	Limestone
Cambrian	941 to 1285	344	Unrecorded
	1285 to 1290	5	Brown limestone and grit
	1290 to 1358	68	White sand (Roubidoux sand)
	1358 to 1363	5	Black shale
	1363 to 1375	12	Flint and limestone
	1375 to 1392	17	White shale
	1392 to 1410	18	Gray limestone

CARROLL COUNTY

Five miles southeast of Braymer there is a well on the Winterroad Farm. A good flow of fresh water was found about 150 feet below

the surface, but salt water came in at the 500 foot level. This well was drilled about 1100 feet and the exact record could not be obtained. Other records from Carroll County do not reach the Roubidoux formation and consequently are of little value in this report. The general conditions are similar to those of southeastern Caldwell County. Fresh water was struck within about 150 or 200 feet of the surface, and from 300 to 500 feet salt water entered the wells. The Roubidoux sandstone probably underlies the county within 1000 or 1200 feet of the surface, but no definite idea of the quality of the water below that level has been obtained.

CHARITON COUNTY

In 1887 a well was sunk 1 mile north of Brunswick for the purpose of striking oil. The depth of this well was 1505 feet and the surface elevation was 712 feet above sea level. At about 300 feet strong salt water was encountered. At a depth of 1400 feet water began to flow, but has ceased since that date and the water now stands within 10 feet of the surface. It is strongly charged with salt and sulphur. The source of this water is probably from the Gasconade sandstone, as the Mississippian limestone was reached 130 feet from the surface.

The city of Salisbury drilled an 852 foot well in 1896. At 150 feet and 210 feet, fresh water was obtained but below 600 feet a strong flow of salt water was struck. Other well records have been reported, but the general conditions seem to indicate that in local coal measure lenses fresh water may be obtained within 200 feet of the surface, and that the deeper waters are too strongly impregnated with salt for domestic use.

COOPER COUNTY

Although in a most favorable location, Cooper County has no wells reported as reaching the Roubidoux sandstone. This sandstone underlies the whole county, ranging from 400 to 900 feet below the surface, and doubtless would furnish excellent water.

GREENE COUNTY

Several deep wells in Greene County obtain excellent water from the Roubidoux formation. The St. Peters sandstone is reached at about 400 feet below the surface and furnishes good water. The Roubidoux sandstone increases the supply at 600 feet. As high as 750 gallons per hour have been pumped without lowering the water level in the well at the Car Shops at Springfield. These wells have been carefully studied by Prof. E. M. Shepard and the following log is copied from his report in U. S. Geological Survey Water Supply Paper No. 195, p. 133.

Log of Well at Car Shops, Springfield, Mo.

		Depth in feet	Thickness of strata in feet	Character of Rock
Mississippian	Burlington	0 to 35	35	Soil and limestone
		35 to 153	118	Gray limestone
		153 to 215	62	Flint and limestone
		215 to 250	35	Limestone
	Chouteau	250 to 280	30	Soft slate or soapstone
		280 to 297	17	Gray limestone
Devonian		297 to 301	4	Light gray sandstone (Phelps sandstone)
		301 to 318	17	Light gray limestone
		318 to 330	12	Flint, limestone and pyrites
		330 to 336	6	Light gray limestone (King limestone)
Ordovician	Joachim	336 to 340	4	Flint and limestone
		340 to 347	7	Gray limestone
		347 to 372	25	White gritty limestone
		372 to 375	3	Fine limestone
		375 to 390	15	Coarse limestone
	St. Peters?	390 to 398	8	Porous sandstone
		398 to 406	8	Limestone and some sand
Cambrian	Jefferson City	406 to 435	29	Bluish brown limestone
		435 to 512	77	Fine flinty limestone
		512 to 522	10	Fine sand
		522 to 532	10	Fine gray limestone
	Roubidoux	532 to 587	55	Very fine sand rock
	Gasconade	587 to 592	5	Brown limestone
		592 to 600	8	Flinty siliceous rock
		600 to 610	10	Very fine white sand rock
		610 to 620	10	Finer sand
		620 to 645	25	Sand
		645 to 678	33	Brownish gray limestone and flint
		678 to 690	12	Reddish brown limestone
		690 to 698	8	Gray limestone and white flint
		698 to 720	22	Fine white sand, sharp grit

HENRY COUNTY

Clinton has for a long time been famous for its artesian wells. In the city there are six wells, the first having been drilled in 1887. This well was owned by Mr. H. P. Faris and the cuttings were saved by Dr. J. H. Britts. A little over a million gallons flow from this well per day, the head rising in a pipe about 12 feet. The bore is 8 inches for the first 400 feet; 5½ from there to the bottom (850 feet).

An excellent supply is furnished the city from these wells although the water has a slight sulphur taste. At Hartwell a well has been drilled within the last two years for a hunting club lake. The depth is 1190 feet, and an abundant supply of good water was obtained.

The following is a log determined from the Clinton well cuttings which were presented to the University by Mrs. J. H. Britts of Clinton, Mo.:

Log of the Clinton Well.

		Depth in feet	Thickness sampled in feet	Character of Rock
Mississippian	Burlington	0 to 40	40	Clay and shaly blue pebbles, well rounded.
		40 to 50	10	White spongy chert, little lime.
		50 to 60	10	White chert, very little lime.
		60 to 70	10	White and blue chert
		70 to 80	10	Gray limestone, decidedly cherty.
		80 to 90	10	White lime, soft, very little chert.
		90 to 100	10	Darker gray lime, white lime and some shale.
		100 to 110	10	Soft gray shaly limestone
		110 to 120	10	Gray limestone, compact (with chert)
	Chouteau	120 to 130	10	White crystalline limestone, no chert.
		130 to 135	5	White crystalline limestone, no chert.
		135 to 160	25	Blue limestone, splintery, some chert.
		160 to 170	10	Blue shaly limestone, splintery.
		170 to 180	10	Blue limestone with little blue chert
		180 to 190	10	Shaly blue limestone with little chert
Devonian		190 to 200	10	Gray shaly limestone
		200 to 210	10	Blue cherty limestone, siliceous.
		210 to 220	10	Gray, white limestone, chert.
		220 to 230	10	Gray shaly limestone, some chert.
Ordovician	Joachim	230 to 240	10	White magnesian cotton rock, no chert.
		240 to 250	10	White magnesian cotton rock, no chert.
		250 to 260	10	White magnesian cotton rock, no chert.
		260 to 270	10	Bluish gray shaly magnesian limestone, slightly siliceous, cherty.
	Probable St. Peters	270 to 280	10	Shaly magnesian limestone with sand
		280 to 290	10	Calcareous, magnesian iron stained sand, about ½ sand, fairly fine.
		290 to 300	10	Same as above, more iron and more chert.
		300 to 310	10	Same, with a great deal of chert (first water)

Log of Clinton Well—Continued.

		Depth in feet	Thickness sampled in feet	Character of Rock.
Cambrian	Jefferson City	310 to 320	10	Sandy, iron stained, hard magnesian limestone, cherty.
		320 to 330	10	Iron stained, hard magnesian limestone, cherty.
		330 to 340	10	Spongy, gray, magnesian limestone, iron stained.
		340 to 350	10	Fine grained magnesian limestone
		350 to 360	10	Fine grained, sandy magnesian limestone.
		360 to 370	10	Same, with chert
		370 to 380	10	Iron stained, sandy, dolomitic limestone.
		380 to 390	10	Gray cherty, magnesian limestone.
		390 to 400	10	Dolomitic limestone
		400 to 500	100	Brown, sandy magnesian limestone with some chert.
	Roubidoux	500 to 525	25	Fairly well rounded pure quartz grains, about 2/3 sand and 1/3 magnesian limestone (water)
		525 to 670	145	Cuttings not taken on account of water pressure
	Probable Gasconade	670 to 700	30	Gray, siliceous, dolomite limestone.
		700 to 800	100	Gray, sandy limestone.
		800 to 850	50	Fine, white sand.

HOWARD COUNTY

Unfortunately this county seems to be underlain by a great salt basin and the waters from the deep formations are strongly impregnated with salt. In the Marshall well at Boon's Lick fresh water was reported to have come in at 1001 feet, but this has later been denied. In the Fayette well (860 feet deep) the water is also highly charged with salt. The salt springs in Howard and Saline counties very likely have their source in the lower formations as the spring water analyses are similar to those of the well waters. This water probably comes from the Roubidox and Jefferson City formations and whether or not the Gasconade formation will furnish fresh water can only be ascertained by drilling through this salt water level.

JASPER COUNTY

The conditions in Jasper County are excellent for deep wells. The Roubidox sandstone is reached from 900 to 1100 feet below the surface and furnishes abundant water. The city of Carthage has five wells varying in depths from 1000 to 1600 feet. The elevation of the well sites is about 730 feet above sea level, and the water rises within 100 feet of the surface. Since the wells have been worked,

the supply seems to have increased. Only about 60 per cent of the total plant capacity has ever been used, and the water obtained is one of the best public supplies in the state.

Webb City also obtains its city water from deep wells. There are five wells ranging in depth from 857 to 1307 feet. The water rises within 200 feet of the surface; the elevation of the pumping station being 970 feet above sea level. About one and a half million gallons of excellent water are pumped per day.

The Carpenter and Schaffer well at Joplin did not obtain a sufficient flow from the sandstone at 1100 feet but drilled on to 1350 feet. Here a good supply was obtained from a porous magnesian limestone. The well has a diameter at the bottom of 8¼ inches; water rises to 115 feet from the surface, and drops to 140 feet when pumped. The maximum daily consumption is about 300,000 gallons. The water contains a magnesian compound which deposits a hard scale in the pipes.

Other wells throughout the county are similar to the Carthage and Webb City wells. The water comes both from sand lenses and porous limestones. It undoubtedly has its source of supply from the Roubidoux formation, and a good quality of water may be had in all parts of the county from this horizon.

JOHNSON COUNTY

No deep wells in this county are known to reach the Roubidoux formation which underlies the county at a depth of about 1100 feet and probably would furnish a good supply of water. Several wells obtain water from local coal measure lenses and from Devonian sandstones.

LAFAYETTE COUNTY

The Higginsville Prospecting Company in 1898 drilled a well in Higginsville. This well is 1512 feet deep with a diameter of 10 inches at the top, and 4½ inches at the bottom. It is cased all the way down. A strong flow of comparatively fresh water was struck at about 656 feet. At 1071 salt water rose within 80 feet of the surface. This water probably comes from the Roubidoux sandstone as in the wells in Carroll, Saline and Howard counties. Fresh water was again obtained at 1371 feet, probably from the Gasconade formation. The casing now leaks and the salt water seeping into the pipes destroys the value of the well.

The city of Higginsville has several wells for city supply, varying from 250 to 800 feet in depth. The last one, completed in April, 1913, is 732 feet deep; diameter 10 inches, and the water rises within 100 feet of the surface. The supply comes from a sandstone lens about 25 feet thick, and the water tastes of sulphur.

LINN COUNTY

The conditions in Linn County are similar to those of Livingston and the adjoining southern counties. Several shallow wells obtain fresh water from 100 to 200 feet below the surface. In Marceline the Roubidoux sandstone was struck at 1104 feet and furnished a large supply of salt water, which rose within 60 feet of the surface. The following log of the Marceline well was obtained from Mr. R. Hawkins of Chillicothe, Mo.

Log of Well at Marceline, Mo.

Elevation, 775 feet. Reported by G. W. Early, Oct. 17, 1907

		Depth in feet	Thickness of strata. feet	Character of Rock.
Des Moines		0 to 20	20	Surface
		20 to 25	5	Sandstone
		25 to 27	2	Clay
		27 to 32	5	Sand
		32 to 50	18	White shale
		50 to 51	1	Coal
		51 to 53	2	Fire clay
		53 to 55	2	Lime
		55 to 57	2	Shale
		57 to 63	6	Sandstone
		63 to 70	7	Slate
		70 to 72	2	Hard lime
		72 to 128	56	Shale
		128 to 130	2	Soapstone
		130 to 140	10	Sandy shale
		140 to 150	10	White shale
		150 to 178	28	Black shale
		178 to 183	5	Sandy shale (gas)
		183 to 233	50	Shale, dark
		233 to 273	40	Limestone
		273 to 283	10	Shelly lime and sand
		283 to 375	92	Lime and flint
		375 to 380	5	White sand
Mississippian		380 to 545	165	Lime flinty
		545 to 547	2	Green shale
		547 to 592	45	Lime
		592 to 594	2	Green shale
		594 to 701	107	Lime—Mississippian
Devonian and Joachim		701 to 704	3	Green shale
		704 to 724	20	Lime
		724 to 729	5	Green shale
		729 to 799	70	Lime, same as above
		799 to 804	5	Green shale
Cambrian	Jefferson City	804 to 850	46	Lime—hard, flinty
		850 to 852	2	Green shale
		852 to 949	97	Lime, same as above
	Roubidoux	949 to 1104	155	White sand (Roubidoux)
		1104 to 2004	900	Lime and sand—same as above

Note: Salt water rose to within 90 feet of the top.

LIVINGSTON COUNTY

There are several deep wells in Livingston County, but most of them obtain water from the coal measure lenses at about the 200 foot level. The Roubidoux sandstone was struck at Chillicothe at 1100 feet below the surface. Three miles east of Chillicothe in the Adams well it was reached between 1000 and 1100 feet. The water in the Chillicothe well was fresh for the first few hundred feet; then became impregnated with sulphur and salt, and later became almost entirely salt and rose within 20 feet of the surface. The company desiring a boiler water could not afford to treat it so the hole was plugged at 134 feet. This vein contains considerable solid matter but has been used with good results. Unfortunately no analysis of the deep water could be obtained as the sample was lost in shipping after the hole had been plugged. In the Adams well the water rose within 75 feet of the surface and was strongly salt, as characteristic of the Roubidoux water in that locality. The following two logs of these wells were furnished by Mr. R. Hawkins of Chillicothe, Mo:

Log of Well at Municipal Electric Light Plant S. W. Corner of City of Chillicothe, August, 1911.

	Depth in feet	Thickness of strata. feet	Character of Rock. Remarks.
	0 to 20	20	Yellow clay with much ground up limestone mixed through it.
	20 to 30	10	Yellow moulding sand
	30 to 124	94	Blue boulder clay with seam of black soft muck about 40 feet from top of it. Caved badly and cased with 13" casing.
	124 to 138	14	First foot sand, balance clean gravel with fresh water of apparent good quality, rose 75 ft.
	138 to 147	9	Gray shale
	147 to 151	4	Dark shale and slate; barren coal seam.
	151 to 244	93	Light shale
Des Moines	244 to 248	4	Black muck; barren coal seam.
	248 to 256	8	Light shale
	256 to 263	7	Dark shale
	263 to 270	7	Gray shale
	270 to 274	4	Limestone
	274 to 301	27	Gray shale
	301 to 306	5	Hard sand
	306 to 321	15	Salt water sand; rose to 35 ft. of surface
	321 to 331	10	Black shale
	331 to 336	5	Fire clay
	336 to 360	24	Salt water sand; rose to 35 ft. of top
	360 to 364	4	Gravel salt water
	364 to 408	44	Shale—light and dark
Mississippian	408 to 565	157	Lime stone, white crystalline and a large portion white flint all the way through it.
	565 to 640	75	Gray limestone

Log of Well at Chillicothe—Continued.

		Depth in feet	Thickness of strata feet	Character of Rock. Remarks.
Devonian and Joachim		640 to 650	10	Shale
		650 to 670	20	Limestone; dark
		670 to 710	40	Limestone, light and dark.
		710 to 820	110	White limestone; this was creamy white and looked like slacked lime when baled out—darker toward bottom.
		820 to 860	40	Dark brown limestone
		860 to 863	3	Sand
		863 to 873	10	Dark brown lime; very hard.
Cambrian	Jefferson City	873 to 935	62	Limestone Water at 883 (salt). This limestone was crystalline and porous and appears to be a magnesian lime very similar to the Trenton oil bearing rock at Anderson, Ind., from comparative tests with acid and also under magnifying galss.
		935 to 945	10	Hard limestone with much sand mixture.
		945 to 955	10	Hard sand
		955 to 961	6	Blue clay shale with boulders
		961 to 1040	79	Boulders embedded in blue clay—these boulders were white flint; gray limestone dark sand rock conglomerate with pebbles of different colors and character carried all the way from the top of clay down. After two days' rest, water rose to 35 feet of top of casing.
	Roubidoux	1040 to 1098	58	Crystalline magnesium limestone varying in fineness and in color every 5 or 6 ft. from gray to yellow and light brown—water bearing in at least part of it. Water rose to 20 ft. of top.
		1098 to 1145	47	Roubidoux sand Apparently a little oil in last limestone. The water had a coal oil smell in the upper part of it but this was thought at first to be caused by oil dropping from the casing. A thick yellow scum rising on the water was thought to be from rust on the casing. Lower down after repeated bailing, sand from the bottom on being washed impregnated the water so that a film arose showing plainly the characteristic peacock colors by reflected light. Oil trace.
		1145 to 1153	8	Dark blue, very plastic clay with black, slaty shale and hard. sandy shale or sand rock; caved badly; sand lower.
		1152 to 1194	41	Section 41 ft.
		1194 to 1205	11	Limestone, impure, sandy and very pyritic.

Note: First casing 80 ft.; slipped 13 inches down about 30 ft.
Second casing, 10 inch to 150 ft.
Third casing. 8 inch to 408 ft.
Fourth casing, 6⅝ inch to 1040 ft.

Log of Well on Farm of C. E. Adam, Sec. 28, T. 58, R. 23.

	Depth in feet	Thickness of strata. feet	Character of Rock. Remarks.
Des Moines	0 to 30	30	Soft yellow clay
	30 to 45	15	Sand rock, yellow and rather soft.
	45 to 56	11	Light clay shale
	56 to 58	2	Hard conglomerate, different colors.
	58 to 61	3	Black shale
	61 to 130	69	Light colored gray shale
	130 to 132½	2½	Sand rock, 2 ft.; coal, 6 in.
	132½ to 190	57½	Light colored shale
	190 to 194	4	Black slate
	194 to 230	36	Light gray, clay shale.
	230 to 238	8	Variegated green and red clay shale; caved.
	238 to 251	13	Dark shale
	251 to 252	1	Limestone
	252 to 297½	45½	Gray clay shale
	297½ to 300	2½	Brown smut
	300 to 348	48	Drab to purple clays and shale of different colors with particles of coal.
	348 to 351	3	Soft, nearly white sand rock with mica particles in rounded grains like mustard seeds and larger.
	351 to 430	79	Black shale. Saline water began at 406 feet in this shale.
	430 to 442	12	Conglomerate mixture, not very hard, with iron pyrites; rather open texture, probably main source of saline water.
	442 to 452	10	Light bluish-white fire clay, very fat; but little sand.
	452 to 481	29	Same as last but darker and more sandy. Cased at 481 ft. with 5⅝-in. casing.
Mississipian	481 to 484	3	White limestone, very white and cherty.
	484 to 522	38	Limestone, white, with flinty layers. Also a layer of white, very soft, rock like gypsum, not affected by hydrochloric acid. Water rose, either from a thin loose stratum, or, more likely, broke through at bottom of last casing above; saline.
	522 to 584	62	Sand rock, flint, fire clay, thin slate; water worn, pebbly all about.
	584 to 596	12	Soft, chalky limestone.
	596 to 602	6	Flint, sand rock and black shale.
	602 to 616	14	Black shale
	616 to 636	20	Gray, soft sandy mixture.
	636 to 645	9	Flint, white sand, blue shale mixture.
	645 to 714	69	Gray, soft sandy mixture.
Devonian and Joachim	714 to 762	48	Darkish joint clay; caved all the way through it. Cased at 762 ft. with 4½-in. casing.
	762 to 766½	4½	White limestone
	766½ to 779	12½	Hydraulic, dark limestone.
	779 to 800	21	Soft white limestone
	800 to 846	46	Hydraulic limestone, dark mud rock.

Log of C. E. Adam Well—Continued.

		Depth in feet	Thickness of strata feet	Character of Rock. Remarks.
Cambrian	Jefferson City Formation	846 to 854	8	White flinty limestone
		854 to 881	27	"Bastard" limestone, dark colored. Water very soft at 861 ft., increasing in quantity probably down to 881 ft. Rose at first to 125 ft. from surface, afterward continued to rise till it reached 90 ft. from surface.
		881 to 906	25	Gray sandstone, fine and hard, with softer, whiter and coarser layers.
		906 to 917	11	Limestone
		917 to 982	65	Mixture, white flint, drab clay and sand rock, varying from fine to rather coarse. Some gas appeared when the bucket reached the top.
		982 to 990	8	Mixture, about 25% consisted of particles of black coal or fossilized organic matter which swelled like coal when burned wet; mashed easily into impalpable powder like lampblack. Remaining 75% rounded coarse sand of different colors, mostly opaque white.
	Roubidoux Formation	990 to 1065	75	Gray sand rock composed partly of white rounded grains of pure silica. Sample from top of stratum shows mixture of angular fragmentary sand and some of the black coaly material from the preceeding stratum. This stratum was soft in the lower part and slightly bluish in color; composed largely of "infusorial" sand. It caved badly and caused suspension of the work. Water was struck probably in the lower part; the exact point is unknown as the water already stood 90 ft. from the surface. The only indication was a rise in the water level to 75 ft. from the surface.
		1065 to 1066½	1½	Angular flinty sand with large mixture of metal flakes of steel color. Also mixed with round white silica sand (infusorial?)
		1066½ to 1076½	10	Same with lack of the metal and mostly flinty or like quartz.
		1076½ to 1101½	25	Pure white silica sand (infusorial?) rounded, nearly uniform in size and transparent like glass when magnified. Sand is fine, like fine cornmeal or granulated white sugar, with remarkable uniformity in size and shape of grains. Did not get through this last formation.

MORGAN COUNTY

Morgan County may receive water from both the Gasconade and Roubidoux formations. The Roubidoux sandstone underlies the northern part of the county varying from 200 to 400 feet below the surface, and out-crops along the streams near the southern boundary. The Gasconade formation lies about 250 or 300 feet below the Roubidoux and should furnish excellent water for this county. A few wells are known to penetrate the Roubidoux sandstone, and obtain a good supply of water although there is a tendency for the sand to clog the holes. This has been observed in the Moser Milling Company's well at Versailles. Small flowing wells are reported near Versailles; the average depth of these being about 200 feet.

NEWTON COUNTY

There are a number of wells in Newton County. Most of these are shallow, and some of them yield flowing water within 300 feet of the surface. At Neosho there is a well 1201 feet deep which flows 50 gallons of water per minute. The water is of an excellent quality containing only 230 parts of solids per million.

The data as to the strata penetrated was obtained from Dr. A. W. Benton of that city. After passing a few feet of clay in drilling, practically pure limestone continued to 275 or 300 feet. From there to 450 feet thin shale beds came in between limestone and flowing water was furnished from a 20 foot bed of shale at 450 feet. (This probably is a Devonian shale.) The water was impregnated with sulphuretted hydrogen; the flow being about 60 gallons per minute. From this level hard flinty limestone predominated, the shale disappearing and interbedded sandstones coming in. Two beds of pure sand were passed through, one at 900 and another between 1100 and 1200 feet. These formations have been classified as the Roubidoux and the Gasconade sandstones respectively. The quality of water gradually changed from the sulphur water of the shale to a fresh water in the lower sandstones.

Practically the same conditions should be expected throughout Newton County.

PETTIS COUNTY

The Sedalia City Water Works has for a long time obtained part of its water from deep wells. In the spring of 1913 arrangements were made to drill three or four new ones in order that the entire city supply might be from that source. These vary in depth from 400 to 600 feet. The Roubidoux sandstone carries excellent

water at about 500 feet below the surface near Sedalia and a little deeper in the northern part of the county.

A deep well in Forest Park, about a mile north of the waterworks wells, was drilled in 1893. This well was 1612 feet deep, but only a partial log was kept and this does not furnish any definite idea of the strata.

SALINE COUNTY

The salt springs and wells in Saline County are believed to receive their water from the Roubidoux formation. The conditions here are similar to those of Howard, Chariton and Lafayette counties. A strong flowing well is located at Malta Bend. It is 1250 feet deep; elevation 690 feet above sea level; diameter 8¼ inches; flow 320 gallons per minute. The water in this well probably comes from both the Gasconade and Roubidoux formations. The Roubidoux sandstone was struck at about 900 feet but casing was only inserted 800 feet below the surface so the water below that level mingles freely, and it is not known whether or not the deeper water was fresh.

At Sweet Springs there is a flowing well, 1074 feet deep; elevation 670 feet; diameter 8 inches; flowing about 840 gallons per minute. Strong salt water came into the well at 604 feet below the surface. The Roubidoux formation carries the salt water but no efforts were made to investigate separately the water below that horizon.

VERNON COUNTY

Vernon County has several deep wells which furnish good water for domestic use. The Nevada Water Company supplies the city of Nevada from two wells 900 and 1000 feet deep respectively. The water comes from both sandsone and porous limestone, and stands within 65 feet of the surface. About 400,000 gallons are pumped per day. This water contains a scale forming compound which is very hard on the meters and water pipes, but otherwise is an excellent water for city supply.

Several flowing and non-flowing wells have been reported throughout this county and most of them are similar to the Nevada wells. The Roubidoux sandstone seems to be reached about 900 or 1000 feet below the surface and carries abundant water.

CHAPTER IV.

ARTESIAN PHENOMENA.

Water that rises in a tube is under pressure. Likewise water in an artesian basin is under a similar pressure and this force is called the artesian head. A water bearing stratum (covered by an impervious layer of material) dipping at a small angle is saturated with water from the outcrop or intake to the place where a well pierces the stratum. At the latter point the water is probably several hundred feet lower than the water at the intake, consequently (water seeking its own level) the difference in elevation is the cause of the water rising in the well. This difference in elevation in feet is the net artesian head, but the actual head working on the rising water is the net head minus all frictional resistances.

The measurement of this actual rise may be accomplished in one of two ways. If the water does not flow out at the surface, it is very convenient to measure the distance it comes from some mark on the surface and knowing the depth at which the drill struck the water formation the rise in the well is easily computed. Should the water flow out at the surface, this same method may be used by extending a pipe up from the drill hole until the water fails to flow out of the pipe, and this distance above the surface plus the depth to the water rock, is the head of rise in the well. However, in the case of flowing wells the last method is troublesome, and it is more convenient to attach a pressure gage to the water pipe. The pressure is read in pounds per square inch. Since a column of water 1 inch in cross-section, 2.3 feet high weighs 1 pound, the pressure reading multiplied by 2.3 equals the number of feet the water would rise above that point of pressure. This plus the depth to the water rock, is the artesian head.

The head of water rising in any well varies according to (1) elevation of the area of supply; (2) elevation of the surface of the well and depth at which water formation is struck; (3) hydraulic gradient due to frictional losses; (4) and in some cases to the age of the well.

Elevation of Supply Area.

It is manifest that to obtain pressure enough for an artesian basin 100 miles or more wide, it is necessary to have the intake well above any point in the basin. This is more forcibly understood when compared to a town water supply using a standpipe. The standpipe is usually placed on the highest point in the town,

and built 100 feet or more high. By this gravity method 100 feet difference in elevation is required to force water through open pipes over a small area. Although in a reduced proportion (due to capillary attraction in the rocks) it is necessary to have a wide difference in elevation to force water with an economical head through rock over hundreds of square miles.

The Missouri field generally fulfills the requisites for a relatively high intake. The largest part of Missouri water is taken into the rocks on the flanks of the Ozarks where the elevation at the outcrop of the porous beds is between 800 and 1000 feet above sea level. As rocks dip away from the intake at about 20 feet to the mile, the elevation of the basin is just about that of sea level in 40 or 50 miles and below sea level beyond that distance from the intake.

Elevation of Well Site.

The water rising in a well in any locality rises from the water bearing stratum, and the higher the surface elevation above the water rock, the further from the surface will the water level stand, other factors remaining the same. When the surface elevation is equal or a little less than the elevation of the intake, a flowing well could not result owing to the frictional losses between the intake and well site. A flowing well can only be obtained where the intake is considerably above the well elevation, and the distance the water has traveled through the rocks not great enough to cause large losses.

As the depth to the water rock increases the height of water rising in the well decreases. This is on account of the increased friction in flowing through the rocks, due to the enormous pressure from the material above the water horizon. In preparing to drill a well it is economical to obtain the lowest convenient spot in order that the water bearing formations will be reached as soon as possible so that the water will rise nearer the surface.

Hydraulic Gradient and Frictional Losses.

The hydraulic gradient is a line which passes through the water level points in a series of wells proceeding away from the intake. It dips away from the intake showing that as the distance increases, the artesian head is diminished. This is not as important a factor as in the pipe line phenomena because of the slow movement of artesian water. Most of the openings in artesian sandstone according to Van Hise* are classed under capillary openings—that is, their maximum circular tubes are 0.508 mm. in diameter, and minimum 0.0012 mm. in diameter. Since the phenomena of artesian flow is

*Monograph 47, U. S. Geological Survey, p. 138.

partly capillary the friction is greatly diminished. Moreover friction varies with the velocity, so with artesian waters which move very slowly the friction is materially reduced. *"Apparently in the exceedingly slow movements of many of the larger masses of ground water the viscosity of water and the friction becomes almost zero per unit area. Evidence of this is furnished by the fact that artesian water flowing through rocks for hundreds of kilometers, the openings of which are capillary, may have nearly the full pressure due to head. For instance the artesian water adjacent to Lake Michigan at Chicago at the early wells, before they became so numerous as to interfere when allowed to flow, had a head 30 meters above the surface, and the feeding area is only about 80 meters above Chicago; yet the water has traveled under ground from 150 to 250 kilometers. The resistance causing the loss of head of 50 meters is to be distributed through this distance; therefore the friction per meter must have approached an infinitesimal amount. In such instances the average movement is exceedingly slow, for it will be shown that to accomplish the first of the above journeys more than a century was perhaps required."

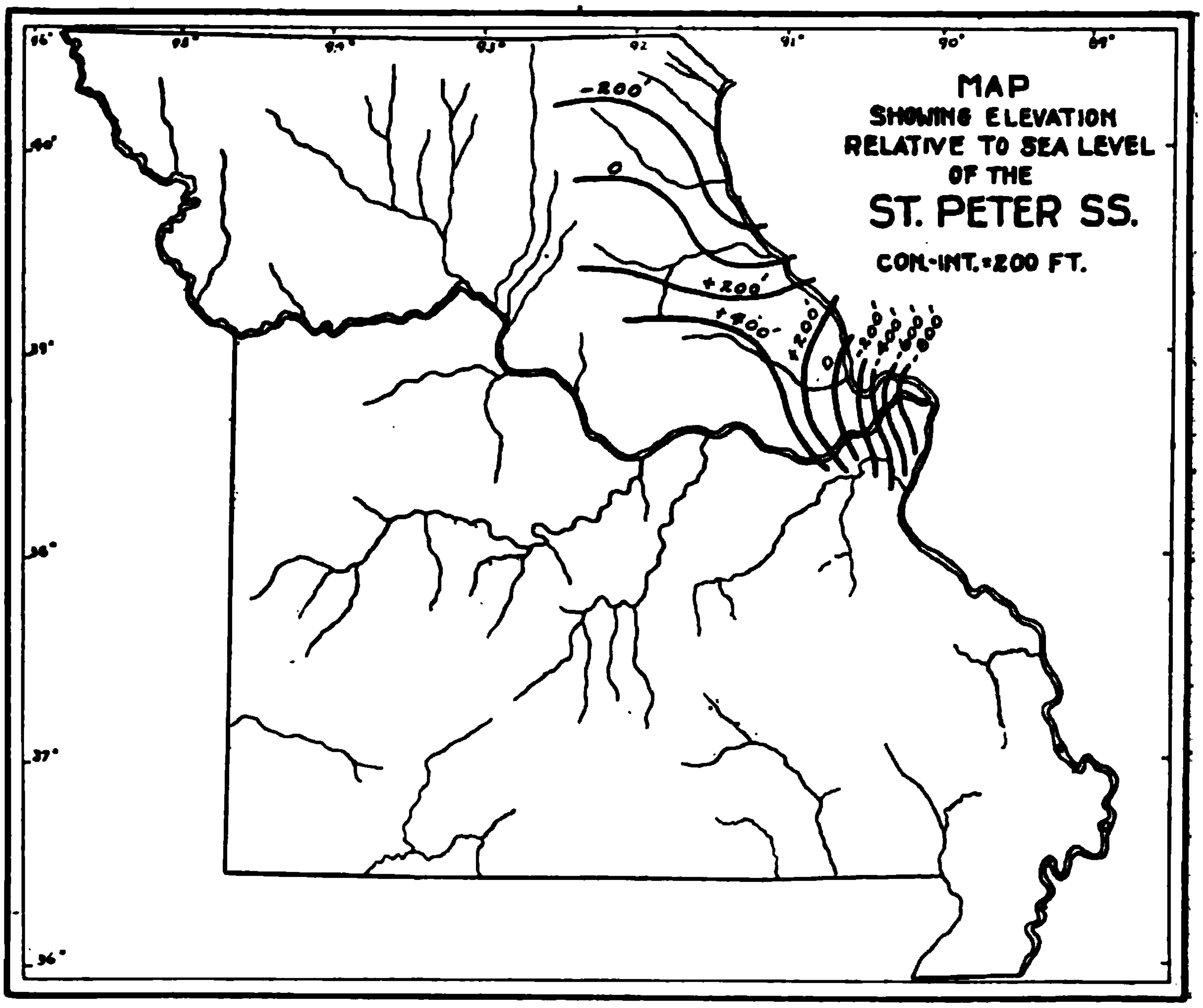
Evidence from the Missouri wells shows that the flow of water is not altogether due to capillary attraction, because of the great loss in head; from 200 to 300 feet in 50 miles. Unfortunately the cuttings of the wells can not furnish data as to the size of the openings, but in many cases drill bits were noted to drop several inches through apparent cavities, showing that the water may often flow through larger openings.

Life of a Well.

It is of importance in engineering problems to know the approximate life of an artesian well. This seemingly simple piece of apparatus for obtaining water from the earth is similar to other machinery and is subject to repairs from time to time, and may finally become worn out.

A deep drill hole several hundred to a thousand feet passes through various kinds of rock material. Some are hard and brittle, others are soft and creeping under the enormous pressure of the rocks above. After the water has worked well aolng the sides of the drill hole these creeping layers thus lubricated, are liable to close in and not only fill up the hole but cause slips and cracks to form in the brittle rock above them. The water will wash away the chips of brittle fragments and finally leave cavities along the side of the hole. The solvent action of the water also helps to form these cavities and thus to shorten the life of the well.

*Monograph 47, U. S. Geological Survey, p. 141.



In order to protect a well and to obtain best results in pumping water free from surface contamination, an iron casing is usually inserted at least part of the way down the deep hole. The care in the construction of this casing is one element that may eliminate future trouble.

It is often feared that a number of wells in a vicinity might over draw the supply of water and the yield of any one well would correspondingly drop. This is theoretically true, but no data as to the number necessary to reduce the flow in any locality has been obtained. At Carthage five wells are operated within a few hundred feet of each other, and no appreciable drop in the first well drilled has ever been noticed.

A well may last hundreds of years, depending upon the local conditions and the care with which it is operated.

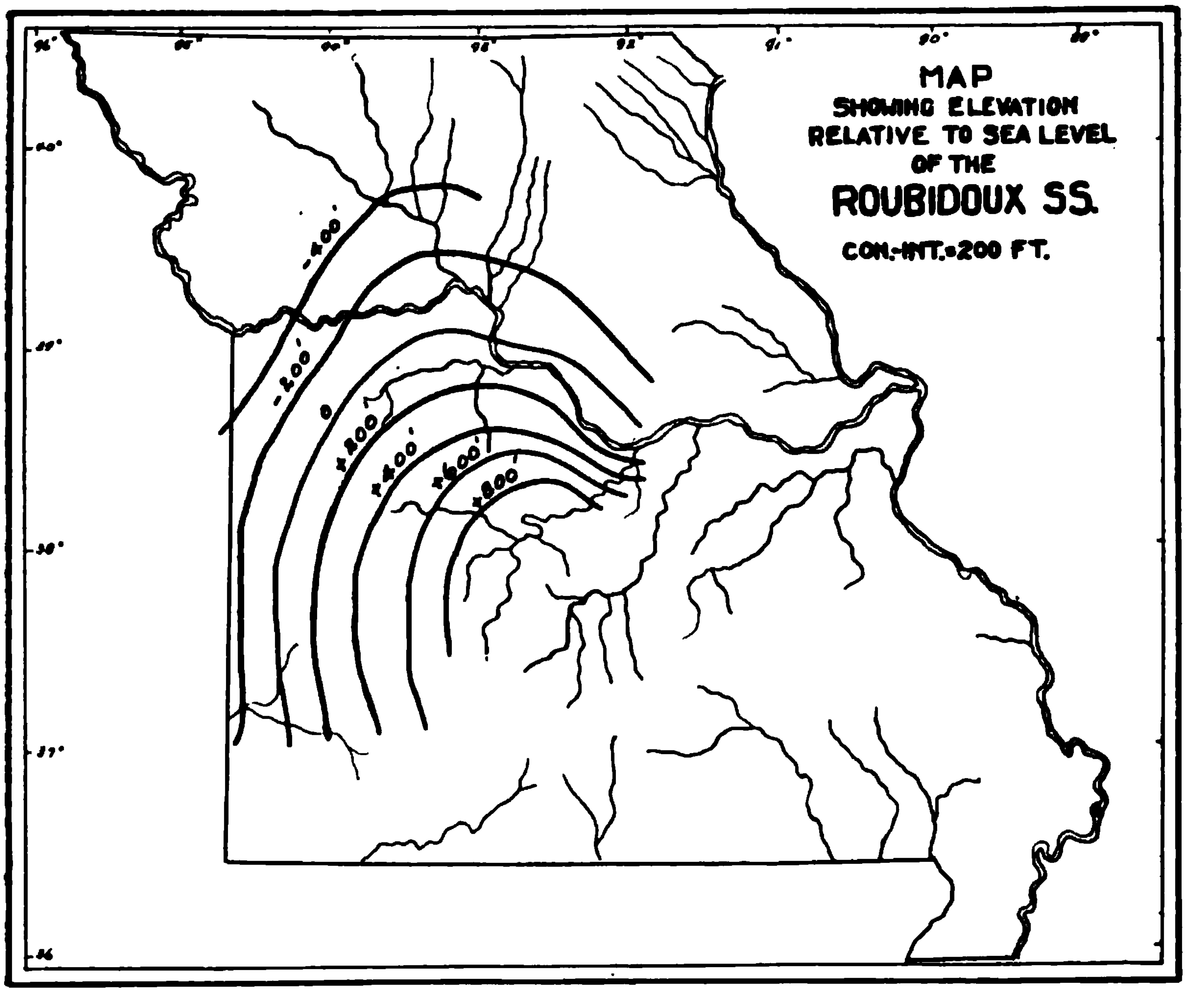
Artesian Phenomena of Missouri.

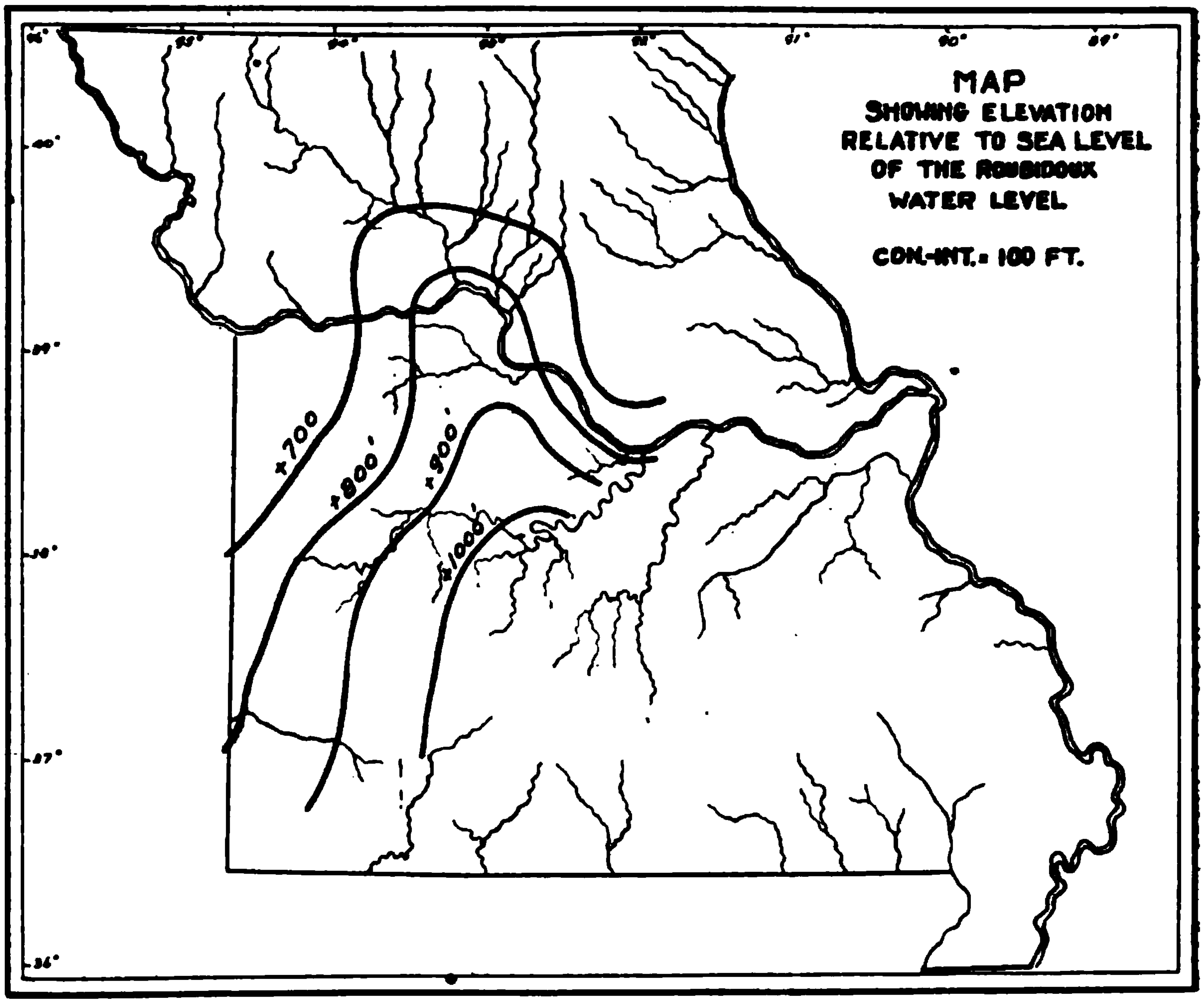
The principal water rocks of Missouri are the St. Peters sandstone, the Roubidoux and Gasconade formations. Each is most important in the area where it is the highest water stratum to furnish a sufficiently good supply. However these areas overlap each other

and several water bearing beds may be penetrated in a single well. This is the case in north central Missouri where salt water is often obtained in local sandstone lenses as far down as the Ozarkian series and finally fresh water reached in the Roubidoux or Gasconade formations.

In order to obtain the specific relation between the heads of two or more water beds it is necessary to measure them in the same well as it is drilled. As nothing along this line has been accomplished, no exact comparisons can be made. These relations would furnish excellent data when one stratum was struck as to whether further drilling would yield a better or less head and the approximate pressure which would then be available.

The contour map showing the elevation of the water level from the Roubidoux sandstone gives an approximate idea of the various heads obtained in different parts of the state from a single sandstone. So little data was collected on the Gasconade formation that a similar map for it was not warranted. A great deal of data was worked over from the supposed St. Peters area but such a variation in water level was found, that a contour map was almost impossible. A peculiar instance of this problem was that





the water head from the sandstone called St. Peters by most drillers increased away from the supply area. A satisfactory explanation for this has not yet been offered. The water level varies from 300 to 700 feet above sea level in the northeast Missouri province.

Effects of Pressure on the Yield of a Well.

The yield of a flowing well varies according to the pressure at the point of discharge, other things being constant. Consequently for the maximum yield for a given locality the lowest available spot should be chosen. Pressure is also the controlling factor in the transmission of water through porous rocks. Experiments have proved that doubling the pressure more than doubles the flow of water. The waters of Missouri are not generally under so great a pressure as those of Iowa and the Dakotas and as a consequence there are not as many flowing wells, but the pressure is large enough to drive water through the rocks and suffice for the needs of deep wells in most localities.

Advantage of a Large Hole.

One of the reasons for so much variation in yield of artesian wells is on account of the difference in diameter of the hole.* "The cross-section of a tube varies with the square of the diameter, thus disregarding other factors, an eight inch pipe would carry 16 times as much as a two inch pipe. But the larger the diameter the less the frictional resistance; hence the difference in favor of the larger pipe is still greater. Taking into account both cross-section and frictional resistance the discharge of pipes varies as the 2.5 power of the diameter."

The yield also depends upon the amount of water stratum exposed in the well. This varies according to the thickness of the bed and the distance penetrated by the drill. When the hole is uncased below the top of the water bed and the entire stratum is penetrated the maximum transmission might be expected. Thus a thick water bed will not only hold and carry more water but deliver more than a thin one.

Effect of Texture and Porosity.

Texture and porosity of the water rock effect the yield of a deep well. Gravels give up their store of water much more rapidly than fine sand. Doubling the size of the effective grains of sand raises the yield by four. Stratified rocks yield their water more readily along horizontal planes and a drill hole is fed from the sides by horizontal currents more rapidly than from the bottom. Texture and porosity both decrease as the rock is buried deeper below other sediments, and this causes a decrease in yield as the water rocks are covered more and more by a vast amount of overlying material.

Hypothetical Problem on the Velocity of Underground Flow.

The Clinton wells get their supply from southern Morgan and Miller counties, a distance of about 50 miles. The average annual precipitation of Morgan County is 38 inches. For an approximate example, assume that 25 per cent or 9½ inches of the rainfall seeps into the ground as ground water at the point of intake. The average porosity of the Roubidoux sandstone is about 10 per cent as measured from hand specimens. Thus without raising the water level in Morgan and Miller counties it is necessary to suppose that the water of each previous year shall have a direct downward movement of 95 inches or 7 feet and 11 inches. The movement of the water along the dip is the cause of the lowering of the water level.

*Iowa Geological Survey Vol. 6, p. 14.

Since the dip of the rock is about 20 feet to the mile, the horizontal component of the water movement each year equals $\frac{5280 \times 8}{20}$ or about 0.4 miles. Therefore to travel 50 miles, or from Miller County to Clinton the necessary time is about 125 years.

This is only a hypothetical case and has many possibilities for incorrect assumptions, but serves to show the general rate of travel of underground waters.

*Van Hise estimated that the rate of flow through the Potsdam sandstone in Wisconsin region was 200 years for a distance of 150 kilometers or about 100 miles.

*Monograph 47, U. S. Geological Survey, p. 585.

CHAPTER V.

COST AND ADEQUACY OF DEEP WATER SUPPLIES.

Comparative Cost of Artesian Water.

The drainage surface of Missouri is such that numerous rivers are well distributed over the state. Cities and towns naturally look to these rivers as the most economical means of obtaining an inexpensive water supply, but lately the demand has been for the best water, purity being considered above everything else. In many cases this has led to the installation of the deep well system; although the deep well can never replace other systems in Missouri as it has in Iowa because of the more general distribution of surface streams. Moreover the artesian conditions are not favorable throughout the entire state of Missouri, and the areas where artesian water can compete with good river supply are limited. In the towns not adjoining suitable rivers in northeast, central and southwest Missouri, the deep well source of supply should be considered and compared with other sources before a town installs a permanent system.

No city supply should be chosen until all possible means have been carefully investigated. Some towns in Missouri have been content with a very deficient river supply, where artesian water could have been obtained (probably not as cheaply) but with a better water and a much reduced possibility of contamination. Yet a town would be unwise to consider deep wells alone and install an expensive plant, when another source might be much more economical all things considered. It is not the purpose of this report to definitely advise any community to install a deep well system, but merely to place it in a proper light, in order that it may receive just consideration. Whatever source may be chosen by a town or corporation, the information as to probable depth, quality and quantity of artesian water will be of value to every locality.

The cost of drilling in Missouri averages from $2.50 to $3.00 a foot for wells not over 1200 feet deep, and over that depth the drilling is a little more expensive. The cost of casing varies with the size of the pipe and a price list may be obtained from any of the standard dealers through their free catalogues. Approximately the prices run as follows.

Inside diameter	Price per ft.		
2″	$0.23	7″	$1.50
3″	.35	8″	1.65
4″	.60	9″	1.90
5″	.95	10″	2.30
6″	1.25	12″	3.00

Under the average Missouri conditions water may be obtained within 800 feet of the ground surface. As the average water level stands at about 200 feet below the surface while being pumped, it is generally necessary to lift the water a distance of from 150 to 250 feet to bring it to the top of the well.

For a practical problem, assume that such a well pumps 200,000 gallons per day, with machinery of 60 per cent efficiency (electric motor-driven pump assumed), where power costs 6 cents per kilowatt hour:

Such a well should be a 10 or 12 inch bore, and the practical cost, including the casing would be about		$2500.00
Cost of installation of machinery		2500.00
Total investment in the plant		$5000.00
Power required to lift 200,000 gals. per day 200 ft.	3861.2 ft. lbs. per second.	
Power reduced to K. W.	5.24 K. W.	
Power necessary with machinery 60 per cent efficiency	8.74 K. W.	
Power cost per year		$4510.00
Cost of operation		4510.00
Fixed charges, including interest, depreciation, etc., estimated at		750.00
Cost of one year's discharge (73 million gals. lifted 200 ft.)		$5260.00
One million gallons lifted 1 foot cost		0.37
1000 gallons lifted 200 feet cost		0.073

Steam power is much more expensive, and has not been considered in this problem, as almost every town with a lighting plant can obtain electrical power more cheaply.

Knowing the conditions for any locality a practical comparison can be made between the cost of artesian water, and that of other water supplies.

Quality of Artesian Water.

Of the many sources of water supply, artesian wells are the least likely to be contaminated with bacteria. Typhoid bacilli are

apt to pass through filtration plants and cause serious epidemics unless the plant is working constantly at its highest efficiency. This demands expert care which most small towns can not and do not afford. The waters from shallow wells and cisterns are never considered free from contamination.

Artesian waters have their source hundreds of feet below the surface and are free from bacteria because these microscopic organisms do not exist at that depth in the absence of light and oxygen. Consequently the only possible means of pollution is from surface waters through a faulty casing. This seldom occurs, but waters from the wells should be tested at regular intervals to ascertain whether or not surface water is creeping in. From the sanitarian's point of view, artesian well water is above suspicion and persons using it may rest assured of its healthful qualities.

Although deep well water is free from living organic matter, it contains a great deal of soluble mineral matter. In most cases this is not too objectional for domestic uses, but often is undesirable for factories using condensers and boilers. Water containing more than 2000 parts per million of mineral matter is unpalatable. This amount may be taken as the maximum allowable in a water supply for city use and particularly for drinking. The general observation and testimony of physicians is that this limit is practical and safe. However it can not be confidently asserted that the use of such waters might not have a deleterious effect upon a few individuals.

The standard for a boiler supply is somewhat different. In this case it is desirable for the water to contain as little soluble matter as possible so that the scale formed in the boiler will be a minimum. It is also necessary that the water should carry a very small amount of suspended matter. The chief difficulty in Missouri artesian water is the large soluble content. No special investigation has been made of the different waters and a discussion for individual localities is impossible. In a number of places deep well water is used successfully for boiler purposes, although it usually demands some treatment.

Objectionable Compounds in Artesian Waters.

The presence of lime and magnesia chiefly in the form of carbonates and sulphates, and occasionally as chlorides and nitrates, renders a water hard. The carbonates cause temporary hardness (removable by boiling) but the sulphates and other compounds cause permanent hardness. It has been shown by chemists that two ounces of soap are neutralized or wasted in each 100 gallons of water for each grain per gallon of calcium carbonate. The lime and magnesium carbonates are precipitated in boilers forming a deposit which can usually be removed by blowing out, unless accompanied

by other scale forming substances. A very hard objectionable scale is precipitated from the sulphates of lime and magnesium under the temperatures occurring in steam boiler operation, especially if the water contains other suspended matter.

Simple Softening Processes.

A simple process of softening water is by chemical precipitation. The carbonates may be removed by the addition of lime, a greater quantity of lime being required in case of magnesium carbonate. Sodium carbonate is used to precipitate the sulphates. Some lime must be added to remove the magnesium sulphate completely. The sodium sulphate resulting from this reaction is very soluble but unobjectionable in the amount likely to be present. The chlorides and nitrates may be removed in the same way as the sulphates.

Another common method of softening water is by heating in a feed water heater. Where the water can be heated with exhaust steam and fed to the boiler at about 200° F., this process is economical and successful in the cases where the water contains the carbonates of lime and magnesium. It is not satisfactory where the water contains the sulphates because these are not precipitated until a temperature in the neighborhood of 300° F. is reached. The maximum temperature to which the water can be heated in an exhaust steam feed water heater is about 200° F.

CHAPTER VI.

IDENTIFICATION OF THE ST. PETERS AND ROUBIDOUX SANDSTONES.

It is the purpose of this chapter to justify the correlation of the first water bearing sandstone on the west and north of the Ozarks with the Roubidoux sandstone. In previous works the first water sandstone encountered has always been called the St. Peters sandstone. The change has been made here for two reasons: first, because of the general absence of the St. Peters sandstone in the western and central parts of Missouri, and second, because of the similar characteristics and close resemblance of the first sandstone in western Missouri to the Roubidoux.

The true St. Peters sandstone extends from the northern part of Jefferson County through the northeastern corner of Franklin County, across the Missouri River through Warren and Montgomery Counties. It probably underlies the northeastern corner of Missouri and connects with the St. Peters sandstone of Iowa. The formation extends into Callaway County where it pinches out, becoming discontinuous. In southern Boone County the St. Peters occurs in synclines at the top of the Jefferson City formation and the connecting beds between the synclines were removed before the overlying Devonian was deposited. The width of the sandstone in the synclines observed was always less than 1000 feet.

Throughout Moniteau and Morgan Counties, especially around Versailles, this sandstone is known to outcrop in patches, but nowhere to form a continuous bed. Five miles south of Sedalia synclines of sandstone similar to those of Boone and Callaway Counties were found at the top of the Jefferson City formation. Here the sandstone was only a few feet thick and the maximum width noted was about 35 or 40 feet. South of Sedalia no continuous sandstone in the horizon of the St. Peters has been described. This evidence shows a decided thinning of the St. Peters sandstone west of Montgomery County; that the area of central Missouri at least as far west as Sedalia was once covered with this sandstone, but that it was removed by erosion, excepting in the synclines, as far east as Callaway County, before Devonian time. At any rate the St. Peter sandstone does not outcrop in a continuous bed anywhere west and south of this county.

A formation may not outcrop in a region and still form an important water bearer for that region. Definite determination of this may be made by a study of the well sections throughout the area.

In the Wabash R. R. well section at Moberly there is a water bearing sandstone at 642 feet below the surface. The city wells also obtain water from about the 600 foot level. This sandstone furnishes excellent water but the quantity is limited. Another sandstone was encountered, according to Dr. Shepard,* at 1105 feet below the surface. Dr. Shepard has called this second sandstone the St. Peters, while in this work the one at the 600 foot level was given that name.

In the section by Dr. Shepard there have been inserted 95 feet of Niagarain, 234 feet of Hudson and 131 feet of Trenton above the second sandstone. None of these formations has been reported in any section west of Callaway County, and they do not average so great a thickness outside of Pike County where they reach a maximum for Missouri. The first water sand comes into the section just below the Devonian which is the proper place for the St. Peters sand provided the upper Ordovician and Silurian formations are absent. As shown in the previous paragraphs these formations do not outcrop west of Callaway County, and west of Pike County rarely total 100 feet in thickness.

In the Columbia well section no trace of the St. Peters sandstone was found. The Centralia section shows the Roubidoux sandstone at 1000 feet below the surface with thin lenses of sand between 500 and 600 feet, but bearing no important water. In the Marceline section the Roubidoux sandstone occurs at 1104 feet below the surface. This is identified as the Roubidoux sand because of the large amount of magnesian lime above the sandstone, a condition agreeing exactly with that of the Chillicothe section. The last evidence is almost certain proof, because the only magnesian limestone above the Jefferson City formation is the Joachim which seldom reaches 50 feet in thickness. Consequently where a sandstone is encountered below 200 or 300 feet of magnesian limestone it can be referred with certainty to the Cambrian and in the Moberly section of Shepard there is nothing in the description of the various strata to influence the classification to the contrary. The limestone above the sand is flinty and blue corresponding readily to the Jefferson City limestone above the Roubdoux sandstone. Assuming that the second sandstone at Moberly is the Roubidoux, it then follows a general northwest dip from Centralia (115 ft. below sea level) to Moberly (220 ft. below sea level) to Marceline (250 ft. below sea level). This dip is small, but the line along which the dip is measured is parallel to the axis of the northwest-southeast trough of the coal measures extending down into Audrain and Callaway Counties and little dip is to be expected. Moreover it is better to assume

*U. S. Geological Survey, Water Supply Paper, 195, p. 102.

that the rocks in this district dip uniformly, corresponding with the surface formations, until definite proof has shown the conditions to be different.

In a Higginsville* section, Dr. Shepard has placed the St. Peters sandstone at 1071 feet and the Roubidoux at 1371 feet below the surface. It is the opinion in this work that the Roubidoux is the sandstone at 1071 and the Gasconade at 1371. The reasons for this are similar to those in the Moberly section. One hundred and ninety-five feet of Kinderhook and 281 feet of Trenton are placed above the so-called St. Peters sandstone. The Mississippian formations are exceedingly thin in this part of the State, and the Kinderhook rarely equals 50 feet in any section along the outcrop. The Trenton is nowhere present this far west in Missouri.

†Dr. E. O. Ulrich gives a section of a Kansas City well with the St. Peters sandstone occurring at 1321 feet below the surface. Granite occurs at 2400 feet in the same; the coal measures are 750 feet thick. Here the Mississippian and Devonian formations which rarely equal 300 feet along the outcrops nearest this section, have been expanded into 600 feet, and a thin pinching sandstone (the St. Peters), very seldom seen along the outcrop has been given a definite place, while the 2000 feet of continuous Cambrian sediments have been cramped into half that amount.

West of Moberly no St. Peters sandstone furnishes water and in most wells there is almost a total absence of sandstone until the Roubidoux is reached. From the contour map showing elevation of the Roubidoux sandstone it is seen how regularly the sandstone dips away to the west and northwest. In each new well section in western Missouri the sandstone has been called the Roubidoux because of the gentle northwest dip agreeing with neighboring sections, the amount of magnesian lime above the sand, the character of the formations, and the similarity of the water. For these reasons the author thinks that the most logical conclusion is that the St. Peters sandstone is absent, and that the first important water sand of western and central Missouri is the Roubidoux.

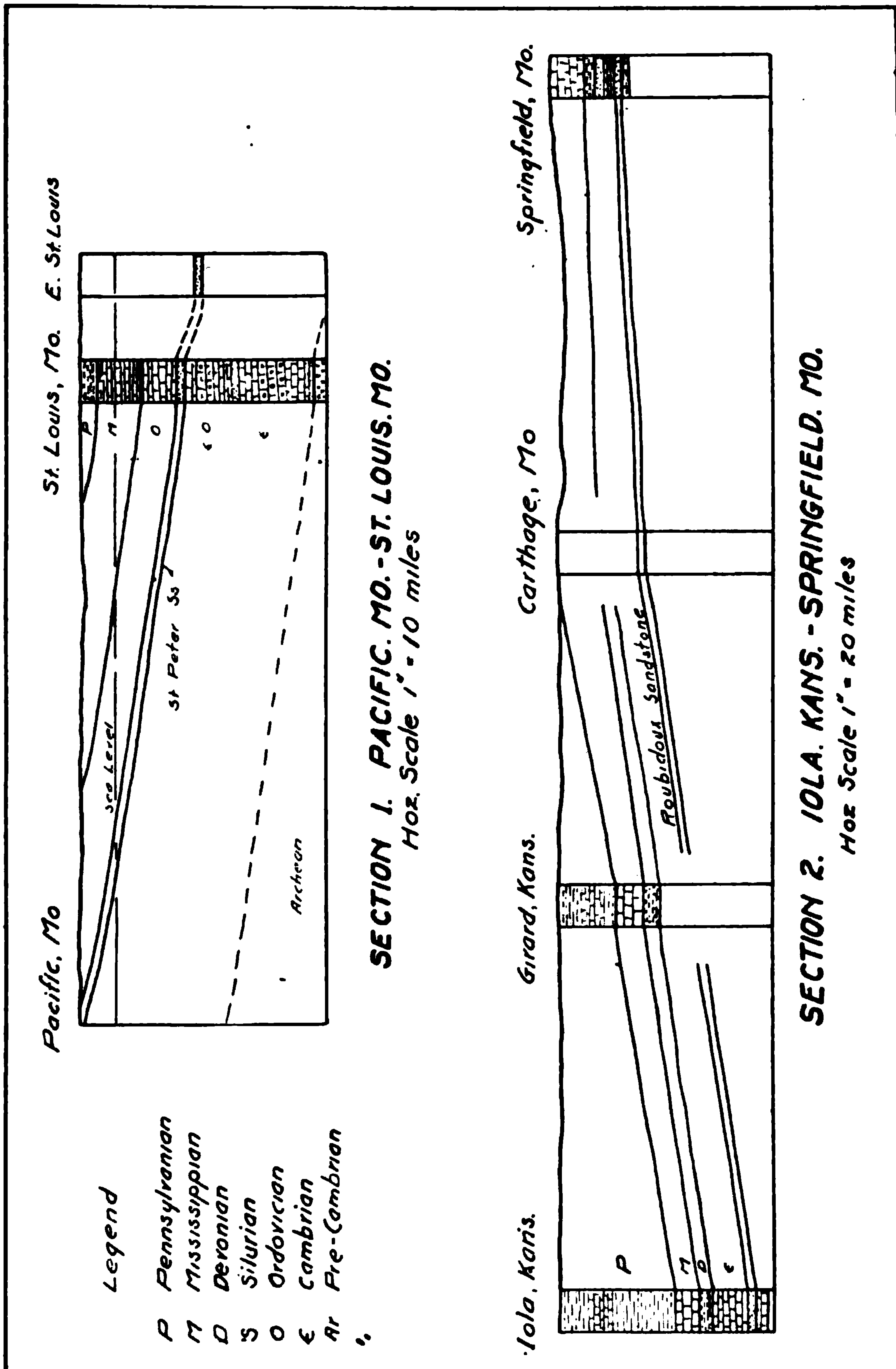
*U. S. Geological Survey, Water Supply Paper, No. 195, p. 38.
†U. S. Geological Survey, Water Supply, Paper No. 195, p. 86

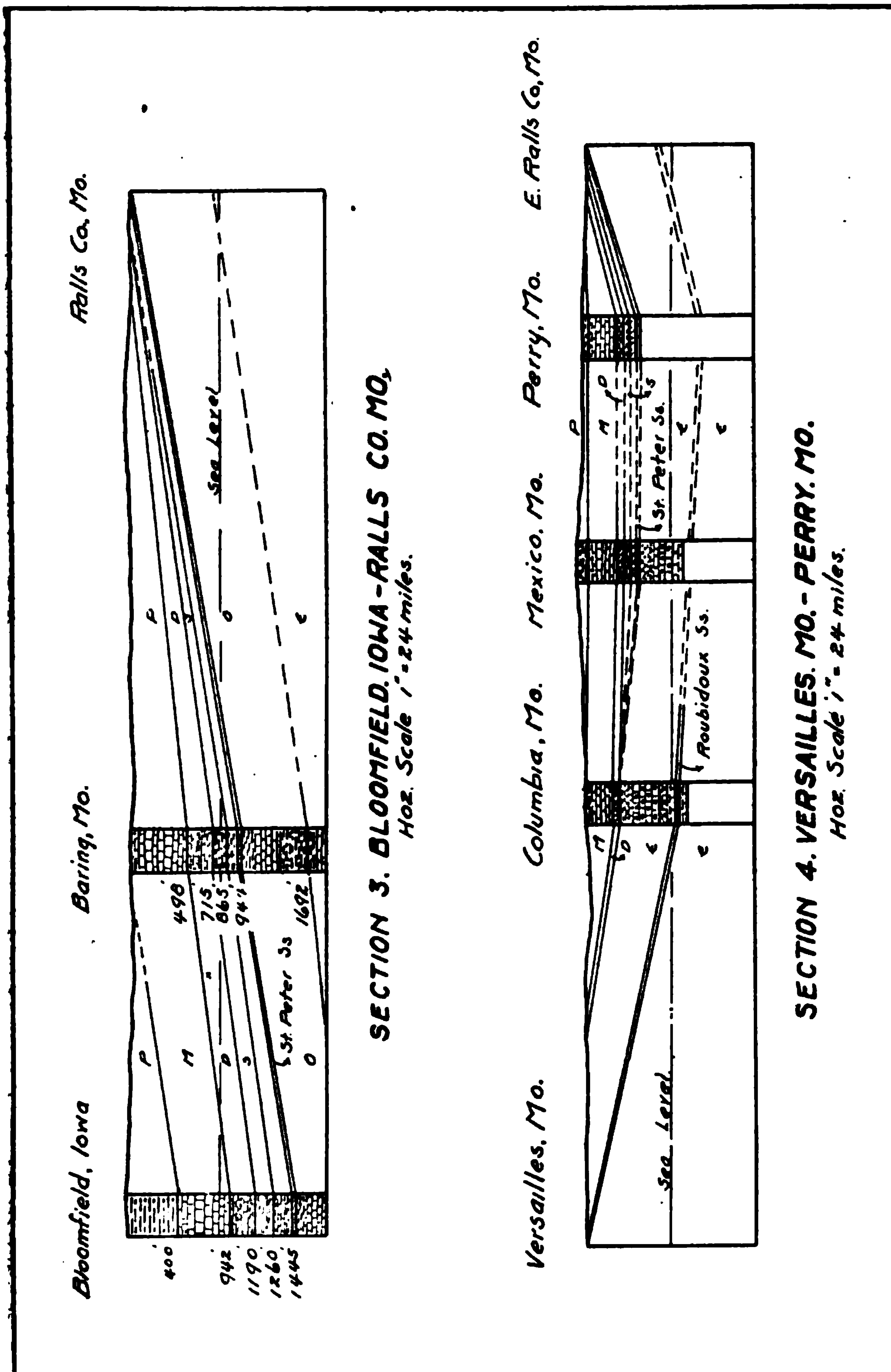
NOTES ON THE SECTIONS.

The following sections are to give a general idea as to how the rocks dip over large areas of the state. The vertical scale in all the sections is 1 inch equals 2000 feet of strata; the horizontal scale varies with the individual drawing. The sandstones carrying the water have been conventionalized, with small dots indicating sand, and have been labeled especially in order that they may be easily traced.

The logs of the sections in Missouri are given under the corresponding counties. The logs outside Missouri have the following references:

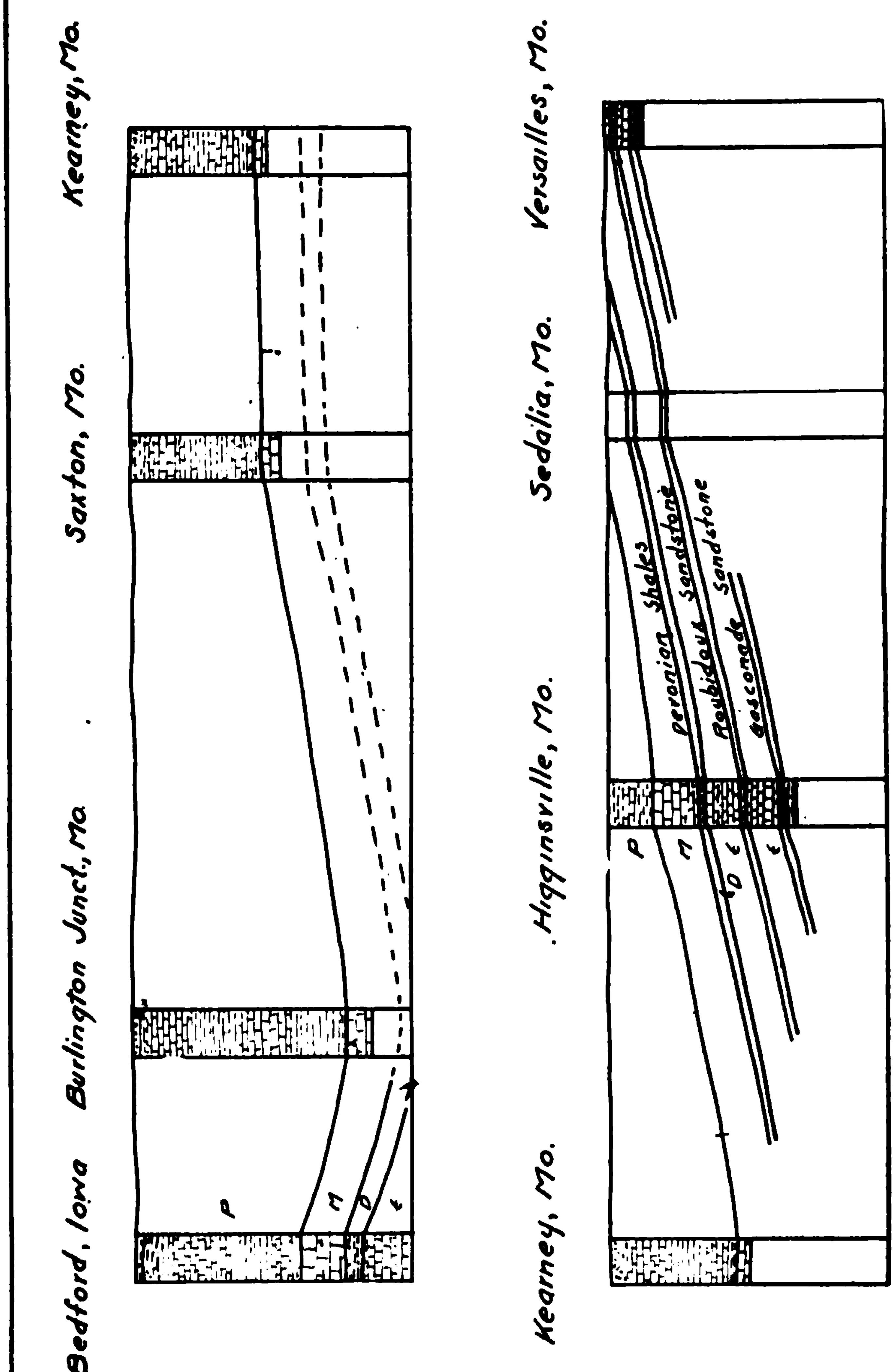
Iola, Kansas Section, Univ. Geol. Sur. Kansas, Vol. 9, pl. 16.
Bedford, Iowa Section, Iowa Geol. Sur. Vol. 21, p. 1183.
Bloomfield, Iowa Section, Iowa Geol. Sur. Vol. 21, p. 624.


Legend
P Pennsylvanian
M Mississippian
D Devonian
S Silurian
O Ordovician
€ Cambrian
Ar Pre-Cambrian
Pacific, Mo
St. Louis, Mo
E. St. Louis
Sea Level
St Peter Ss
Archean
SECTION 1. PACIFIC. MO.-ST. LOUIS. MO.
Hoz. Scale 1" = 10 miles
Iola, Kans.
Girard, Kans.
Carthage, Mo
Springfield, Mo.
Roubidoux Sandstone
SECTION 2. IOLA. KANS.-SPRINGFIELD. MO.
Hoz Scale 1" = 20 miles

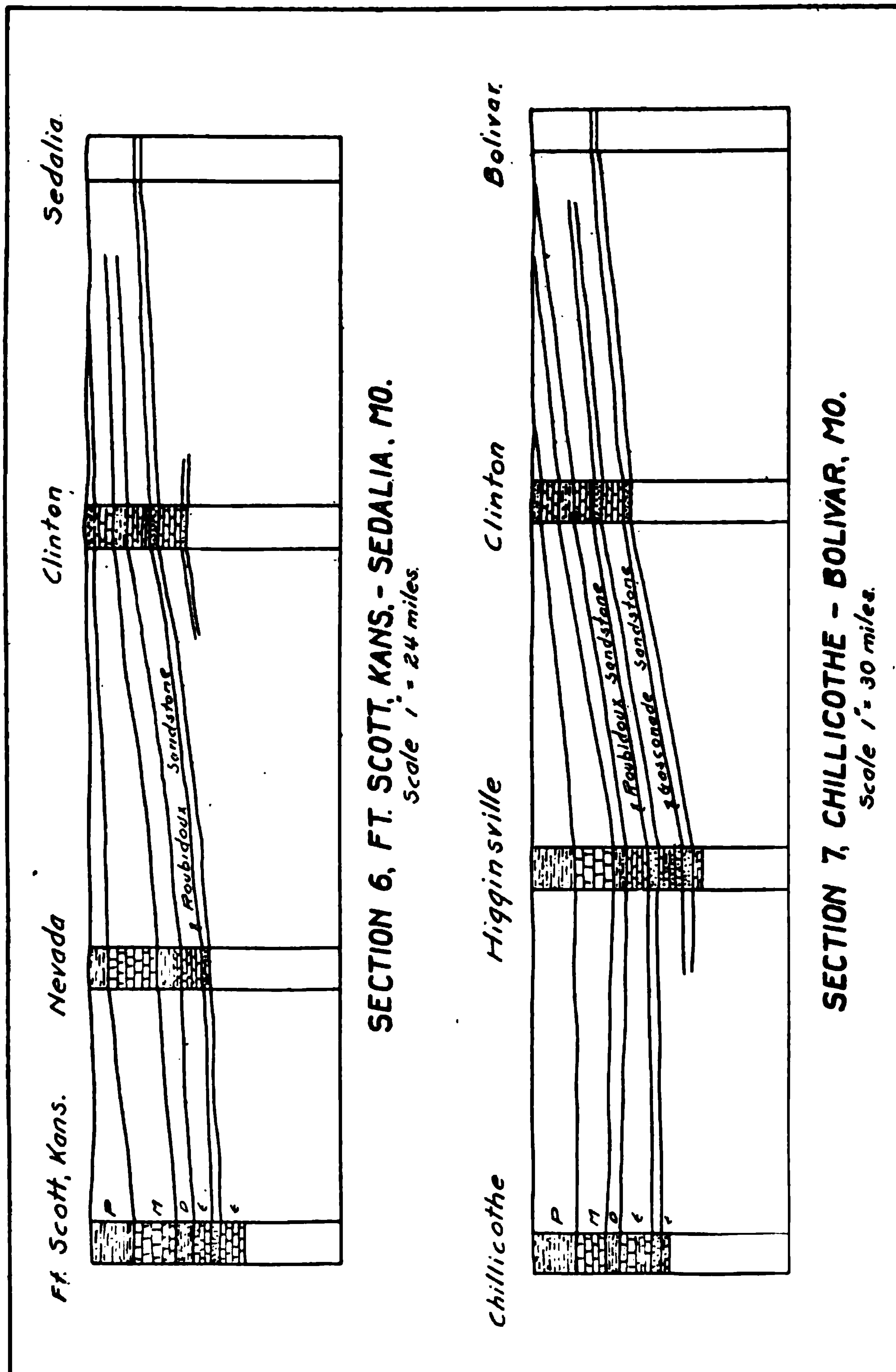


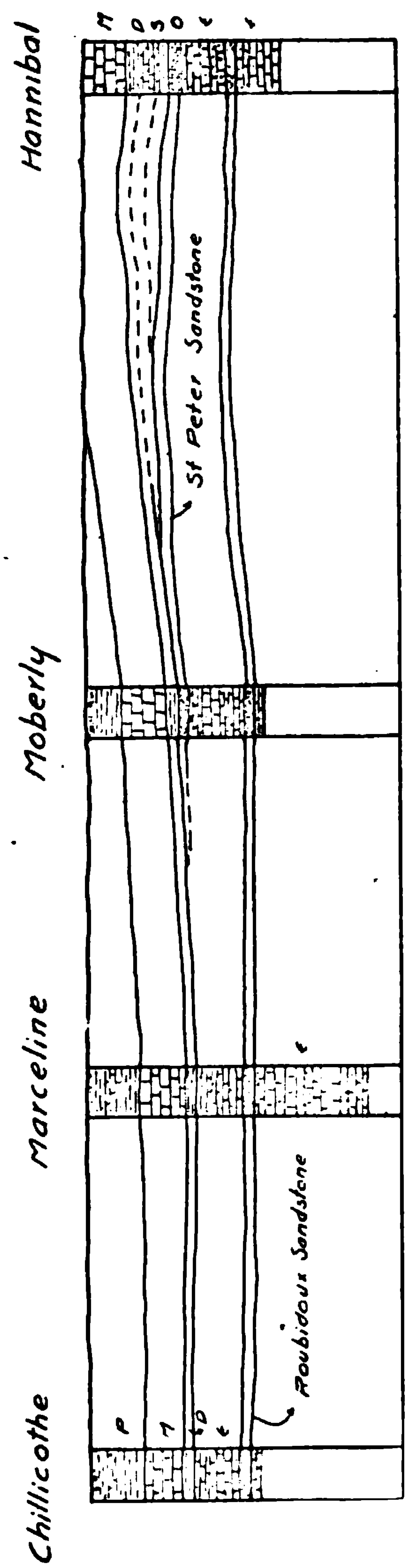
SECTION 3. BLOOMFIELD, IOWA-RALLS CO. MO.
Hoz. Scale 1" = 24 miles.

SECTION 4. VERSAILLES, MO.-PERRY, MO.
Hoz. Scale 1" = 24 miles.



SECTION 5. BEDFORD, IOWA - VERSAILLES, MO.
Hor. Scale 1" = 24 miles.


Ft. Scott, Kans.
Nevada
Clinton
Sedalia
Roubidoux Sandstone
SECTION 6, FT. SCOTT, KANS. - SEDALIA, MO.
Scale 1" = 24 miles.
Chillicothe
Higginsville
Clinton
Bolivar.
Roubidoux Sandstone
Gasconade Sandstone
SECTION 7, CHILLICOTHE - BOLIVAR, MO.
Scale 1" = 30 miles.



SECTION 8. CHILLICOTHE-HANNIBAL MO.
Scale 1" = 24 miles

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EDITED BY

E. A. FESSENDEN

Director, Engineering Experiment Station

Issued Quarterly

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FRICTION TESTS OF LUBRICATING GREASES AND OILS

BY

A. L. WESTCOTT

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
December, 1913

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and four research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

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FRICTION TESTS OF LUBRICATING OILS AND GREASES.

INTRODUCTION

The objects to be gained by the lubrication of the bearings of machinery are twofold.

> 1.—By the interposition of a thin layer or film of oil between rubbing surfaces, they are kept partially separated, and wear due to rubbing contact is greatly reduced. The parts last longer and repair expenses are reduced by efficient lubrication.
>
> 2.—The coefficient of friction between two surfaces in sliding contact is greatly reduced by lubrication. The lost work of friction is therefore much less in a well oiled machine than in the same machine running without lubrication. Efficient lubrication thus reduces the amount, and therefore the cost, of the power required in a given plant.

The saving in repair expense and in cost of power is partially offset by the cost of the lubricant. The best lubricant for a given purpose is that which will give the maximum net annual saving.

Let **P** = the saving in friction horsepower due to lubrication.
M = the cost per year of one horsepower.
R = Annual saving in repair due to lubrication.
O = Annual cost of lubricant necessary to attain these savings.
S = Net annual saving, in dollars.

$$S = M\,P + R - O$$

That lubricant is best in any case for which S will have the largest value.

The friction reducing value of a lubricant may be determined by laboratory tests upon an oil testing machine. Its value to reduce wear in bearings is best determined, probably, by actual trial over a considerable period of time. But it is probably reasonable to assume that the wear of bearings is proportional to the coefficient of friction.

The coefficient of friction with a given lubricant varies greatly with the conditions under which it is used. The temperature of the bearing, the intensity of bearing pressure, and the speed of the surface of the journal are all factors in determining the coefficient of friction.

The tests of each lubricant reported in this bulletin were made under a great variety of conditions as to bearing pressure and temperature, to determine their relation to the coefficient of friction. These tests consist of:

> 1.—Tests of lubricating greases, made by the writer, or under his direction, to determine their lubricating value under a variety of conditions as to temperature, load on bearing, journal speed, and method of applying the lubricant.

2.—Tests of a number of engine oils and gas engine cylinder oils, under various loads and temperatures. These tests were made by Mr. G. F. Klein, and Mr. I. Dunbar as a thesis investigation, in the mechanical laboratory of the Department of Mechanical Engineering, University of Missouri, in the spring of 1913. The writer has carefully checked the computed data of Messrs. Klein and Dunbar, and presents it in a much condensed form.

TESTS OF LUBRICATING GREASES.

Cup greases are made by a process of saponifying some animal or vegetable oil, as cotton seed, lard or tallow. To the soap thus formed is added sufficient mineral oil to give the desired consistency. Manufacturers supply greases of several consistencies, adapted to different conditions of lubrication, each consistency or density having its number.

Fig. 1. Oil Testing Machine.

While grease lubrication is applicable to all sorts of machinery except steam and gas engine cylinders, it has its own special field where it has a marked advantage over oil. This field is machinery whose operation is intermittent, such as cranes and hoisting machinery. Grease cups of proper design will supply ample lubrication to the bearings of such a machine. They require no attention except to fill with grease when empty and, if of the hand compression type, to force grease into the bearing perhaps once or twice a day. No lubricant is wasted when the machine is not in operation, as is likely to be the case if sight feed oil cups and liquid lubricant are used.

It was the purpose of the investigations which form the basis of this report to test a number of greases for coefficient of friction and general suitability as a lubricant under a variety of conditions as to bearing pressure, temperature, and method of application of the grease.

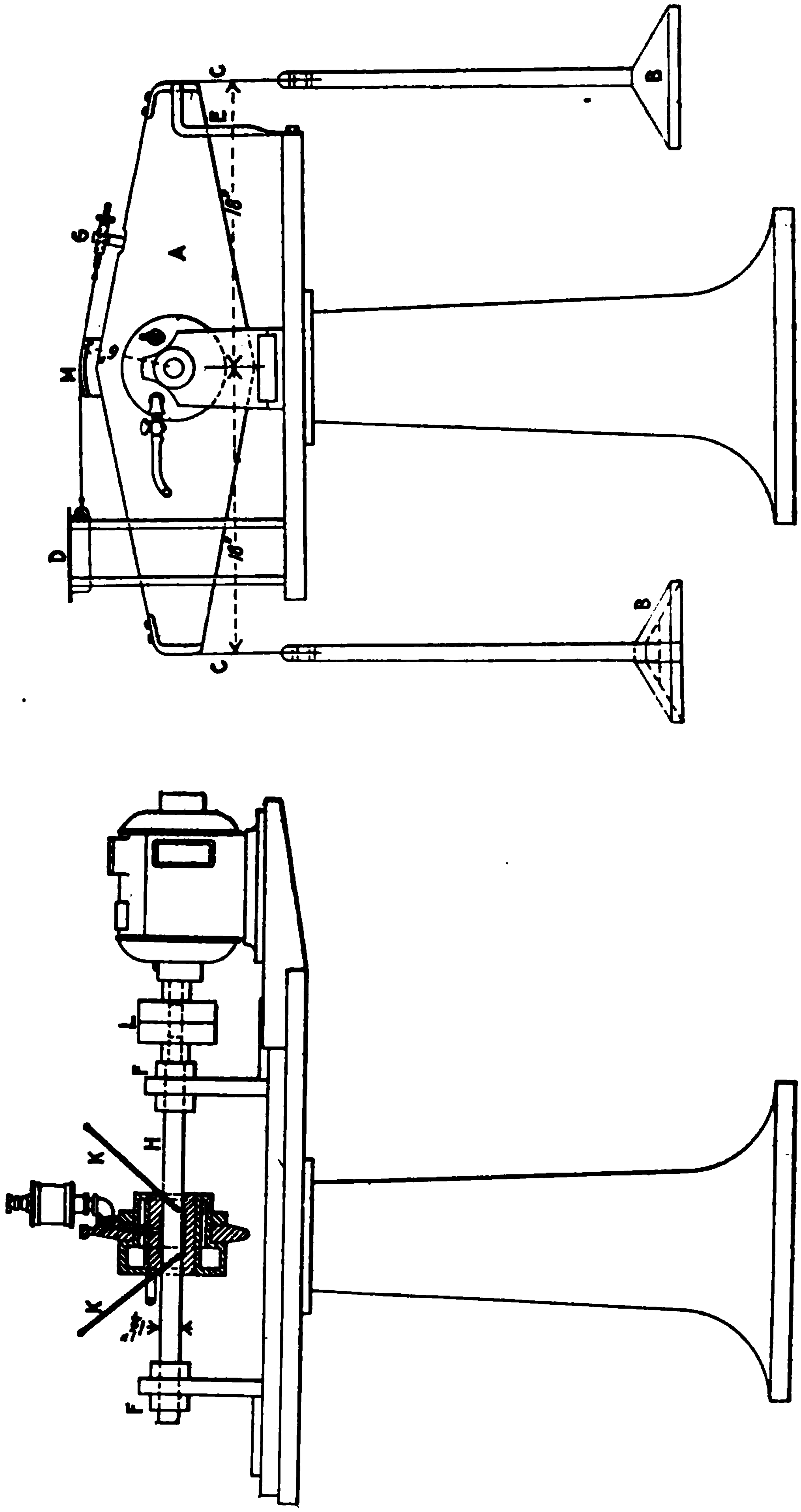


Fig. 2. Oil Testing Machine.

THE TESTING MACHINES

Tests for coefficient of friction were made upon a Golden oil testing machine. Fig. 1 is a general view of this machine, shown in the side and end elevations in fig. 2. The bearing consists of a babbitted sleeve which is fitted to a shaft H, fig. 2. This shaft runs in roller bearings F, and is driven by a motor through the coupling L. The motor is arranged with a reversing switch, so that it may run in either direction as desired. A cast-iron beam, A, is bored out at the center of its length to fit the bearing, to which it is fastened by screws. The ends of this beam are circular arcs struck from the shaft center. Flexible bands, C, are attached to A, and support the weights B, by means of which the load on the bearing is applied. The casting which forms the bearing is cored out so as to provide a space or jacket in which cold or hot water, or steam, may be circulated in order to control the temperature. At D a spring balance is supported upon four vertical rods that are screwed into the machine top. This balance is connected by means of a thin strip of spring steel to the post with screw adjustment at G. The steel strip leads over a part, M, cast on the upper side of A, and machined to form a circular arc whose center is the center of the shaft. The radius of this arc is 6 inches, and the height of the balance is such that it exerts a pull always in a horizontal direction. The weight on the end of the beam opposite to D must be made a little greater than that on the adjacent end, so that a positive pull will always be exerted whichever direction the motor is running. A pointer, E, attached to one end of the table top, enables the operator to bring the beam to any desired angular position. Holes are drilled in each end of the bearing for the insertion of thermometers K, the bulbs of which are brought close to the side of the journals, so as to get as nearly as possible a correct indication of the bearing temperature.

The formula for coefficient of friction is deduced as follows:

Let W = the total load on the bearing, pounds.
Let P = the pull on the spring balance, when running in a clockwise direction, pounds.
Let P_2 = pull on balance when running anticlockwise.
Let D = diameter of journal, inches.
Let ϕ = coefficient of friction.

$$\phi W \frac{D}{2} = 6 \frac{P - P_2}{2}$$

$$\phi = (P_1 - P_2) \frac{6}{WD}$$

For any load, W, the constant $\frac{6}{WD}$ may computed once for all, and the formula takes the form,

$$\phi = C (P_1 - P_2)$$

As originally constructed, the machine differed in several details from that which is shown in fig. 2. Instead of the post and screw adjustment at G, the balance was connected by a light chain to a pin at M, the idea being to take up or let out the chain link by link as required. Also the weights B were suspended by chains at C. It was found that these chains were a very unsatisfactory arrangement. It was necessary, in order to get reliable data, to keep the beam always in exactly the same angular position. A very slight change in the position of the beam would make a considerable difference in the pull on the balance. A chain consisting of a series of rigid links is not sufficiently flexible for the purpose. Changes in the angular position of the beam produced slight changes in the radii to the center lines through the weights B, and this of course meant an upsetting of the condition of equilibrium between the pull of the balance and the frictional turning moment. It was necessary, therefore, to adjust the beam position with great care, so as to be exactly the same when running in each direction. The pointer E was added for this purpose. Later, the chain hangers were replaced by thin steel bands at C. This change produced a marked improvement in the operation of the machine. It was still found to be desirable to keep the beam in one position, and to accomplish this better, the screw adjustment at G was added.

The bearing as supplied by the makers was 2 5-8" in diameter and 5" long. With the largest load that the suspending chains would safely carry, this gave only about fifty pounds per square inch of projected area. It was desired to carry the bearing pressures much higher than this. The length of bearing was therefore reduced to 1 1-2", as shown in fig. 3, there being two rings of 3-4" length each. The temperature was determined by a thermometer inserted into the jacket as shown in fig. 3, which also shows the manner of applying the lubricant.

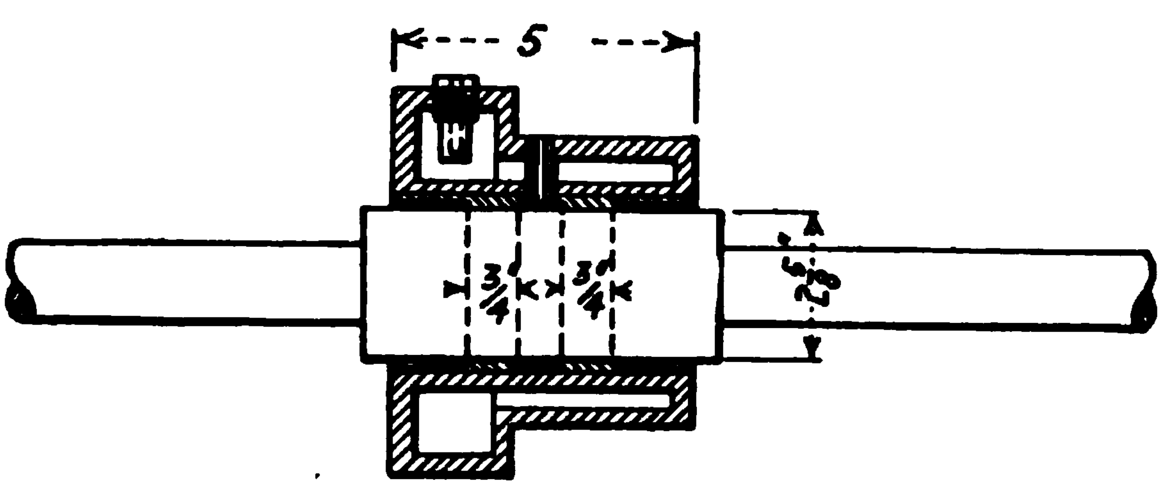


Fig. 3. Bearing.

The bearing of fig. 3 was not very satisfactory. It appeared that the proportion of length to diameter was bad, at least for grease lubrication. The grease was applied by means of a hand operated grease cup of the compression type. The counterbore between the two bearings, where the grease was forced in, was large enough to form a reservoir, and it was thought that the grease would feed in so as to maintain constant lubricating conditions. This did not prove to be the case. After the application of grease the friction, momentarily reduced thereby, would soon begin to increase steadily. A plot of friction against time, under these conditions, would look like the profile of a rip saw; a series of lines inclined more or less steeply to the horizontal, and connected by verticals where the grease cup was operated.

With a view to getting a more satisfactory form of bearing, the change indicated by fig. 4 was made. The diameter was reduced to 1 1-4" and the length increased to 2". This form of bearing proved to be a great improvement. It was still found, however, that intermittent feeding of the lubricant produced variable results for the coefficient of friction. An automatic grease cup, with a spring actuated plunger, designed to give a constant feed, gave much better results.

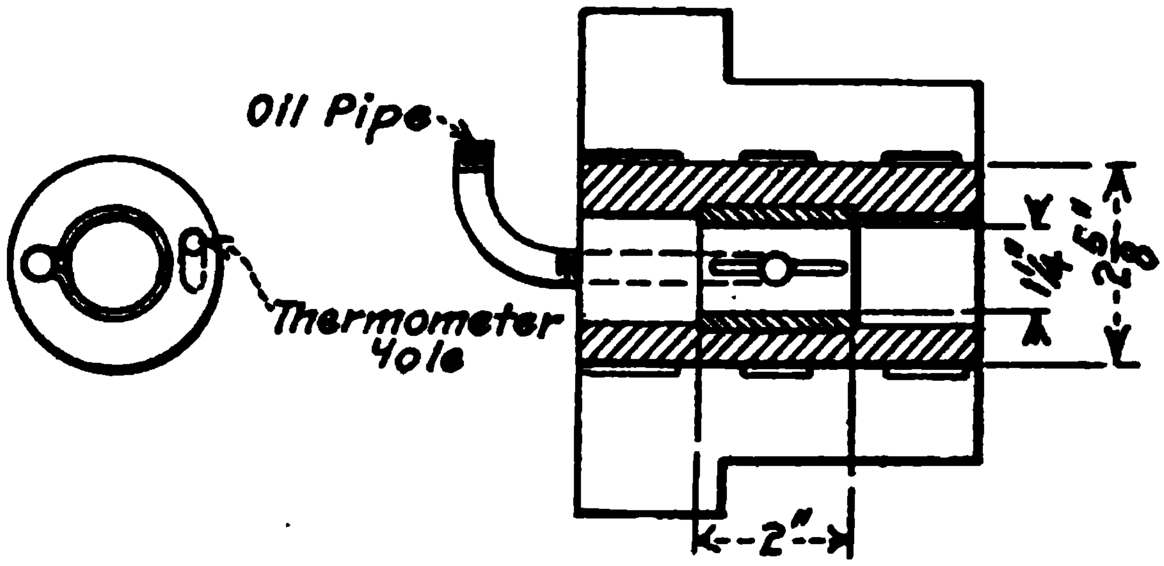


Fig. 4. Bearing.

LUBRICANTS EMPLOYED IN THE TESTS

Three series of grease tests are employed in this report, also tests of an engine oil for the purpose of comparing oil with grease under the same conditions. They will be classified as follows:

> Series A. Tests of cup greases of different densities, using a hand operated grease cup with intermittent feed, the bearing of fig. 3 being employed. The oil tests referred to are included in this series.
>
> Series B. Tests of the same greases as in series A, but with the bearing of fig. 4 employed, and for the most part using a grease cup having a constant feed.
>
> Series C. Tests of six different greases to determine their behavior when applied in a grease cellar on top of the journal, with a view to their flowing into the bearing by gravity when warmed.

Greases from two makers, designated as X and Y, were tested in series A and B. Greases from six different makers, designated by numbers 1 to 6, were tested in Series C.

The consistency of the X greases is indicated by a number; No. 00 being the hardest, No. 6 a semi-liquid, and the other numbers forming a graduated series between. The Y greases are likewise numbered, the hard grease having the highest number, while No. 1 is very soft. No. 5 Y is about the same consistency as No. 00 X.

The greases of Series C may be described as follows:

No. 1. Soft, spongy, fibrous in appearance, bright yellow color.
No. 2. Hard, bright yellow color.
No. 3. Soft, dark brown color.
No. 4. Very hard, light brown color.
No. 5. Extremely hard, looks and smells like soap.
No. 6. A graphite grease, soft, black.

The tests upon each grease in series A and B were carried out as follows:

The load on the bearing was varied. for each grease, through a range of from 46 to 148 pounds per square inch in series A, and from 53 to 154 pounds in series B. For each load, the test was made at temperatures varying through a wide range; beginning at room temperature and gradually increased. During the first three tests of series A, steam was not available for use in the bearing jacket, the elevation of temperature in those cases being due to the heat generated by friction.

In preparation for series C, two oil holes were drilled through the bearing, at angles at about 30 degrees with the horizontal, and on opposite sides of the vertical center line. Oil channels were cut from the inner ends of these holes, to insure the distribution of the lubricant over the bearing surface. A measured quantity of grease was placed in the oil holes, the bearing was loaded to the desired pressure, and the test was started, and continued without the application of any more lubricant until the lubrication failed. Neither water or steam was circulated through the jacket space, the rise in temperature being due entirely to the heat generated by friction. For the purpose of comparing this method of applying the grease with grease cup lubrication, tests were made of the same greases under the same conditions, but feeding the grease by means of a compression grease cup. All the tests of series C were made at one bearing pressure, 114 pounds per square inch.

TEST DATA

The results of Series A are found in tables I to V, and, in graphical form, in figs. 5 to 14; Series B, tables VI to XII, and figs. 15 to 28; Series C, tables XIII to XVIII, and figs. 29 to 34.

The curves plotted from series A and B show, first, the relation between coefficient of friction and temperature of bearing; and second, coefficient of friction and bearing pressure, temperature constant; the second plot being derived from the first one.

The curves representing Series C were plotted differently. Since the length of time that a given test was continued without renewal of the grease in the oil holes is an important factor in determining the value of each grease, time was plotted as abscissae, and coefficient of friction and rise of temperature as ordinates. Each curve shows the complete test of a grease, comprising one, two or three runs, made on different days.

Figs. 35 to 36 show the final set of derived data as to series A and B. For a selected bearing pressure and temperature, the coefficient of friction of each grease number was plotted against the grease numbers as abscissae the purpose being to show the most advantageous grease consistency for a given condition. Plots were thus made for two pressures and for two temperatures for each pressure.

An inspection of the tables and curves brings out some well defined relations. The values of the coefficient of friction shown in series A, made upon a bearing of large diameter and small length, are greatly in excess of values for the same grease when tested on the bearing shown in fig. 4, series B. For example, compare tests of X of grease, No. 3 density, table II, and table VII; and Y grease No. 1 density, tables IV and XII. As has been stated before, the large and short bearing, consisting of two lengths of ¾" each, proved to be a poor form for grease lubrication. The film of lubricant seemed to have little endurance, and the only way to get results particularly with the denser greases, was to force in grease frequently.

Another difference in conditions between the tests of series A and B is the difference in velocity of journal. It will be noted that in series A the surface speed of journal was about double that of series B. The relations between speed of journal and coefficient of friction are discussed in a later paragraph.

The condition of the bearing as to smoothness due to long running seems to have a marked influence upon the coefficient of friction. The test of Y grease No. 2, series B, was made when the bearing was new. The other tests of this series, however, were made subsequently to those of series C, when the bearing had become worn by long use. The effect of this in reducing friction is shown by a comparison of tests of tables X, XI and XII. This comparison shows that No. 2 gave much larger values than either of the other two.

Compare, also, X grease No. 6, table No. VIII, and No. 3, table No. VII. Grease No. 6 was tested upon the bearing shown in fig. 2, immediately after its construction. The new bearing and shaft were made with a clearance of .00075", while the other bearing had a clearance of .003", besides being well worn, as already described. The coefficients of friction for grease No. 6 are larger than those of No. 3, due doubtless to the closer fit of the bearing on the journal and the newness of the bearing.

The effect of a rise of temperature upon the coefficient of friction is almost always the same. The curves show this very clearly. The fluidity of a lubricant is increased by warming it, and its viscosity is decreased. This results in decreased friction up to that point where the bearing pressure is sufficient to overcome the tenacity of the oil film, so that there is contact between the rubbing surfaces. The tests do not indicate that, within the limits of bearing pressure which obtained, there is any disadvantage or danger of cutting the bearing incident to a temperature of 150 degrees F. In some instances the temperature was carried as high as 200 degrees, and as long as there was an ample supply of lubricant to the bearing, no harmful effects were noted. The "hot box" of practice occurs because the lubrication of the bearing has failed; the former being the effect of increase of friction due to the latter. There is nothing intrinsically objectionable in a bearing temperature much higher than is commonly permitted in practice, if good lubrication obtains; and these experiments show that much may be gained in the way of decreasing the lost work of friction.

The tests of series C served to show that the oil hole method of applying grease to the bearing is inferior to the method of forcing it in by means of a grease cup, the coefficients of friction in the former case being much larger than in the latter. An exception is noted in case of grease No. 4 where the advantage lies with the oil hole method. If instead of a small oil hole, a grease reservoir extending the length of the journal had been used, it is possible that the results of the comparison might be different.

Greases Nos. 1, 2 and 3 made a fair showing. Nos. 4, 5 and 6 did very poorly. In each of these cases the grease placed in the oil holes did not flow sufficiently to prevent the bearing from running dry. Two of these failures, Nos. 4 and 5, were extremely hard greases; while No. 6 was a soft graphite grease. In cases of Nos. 1, 2 and 3, two or more runs were required to use up the grease, it being not always convenient to make one continuous run. An inspection of the curves plotted shows that as a rule the coefficient of friction was high at the start, decreasing after a time as the bearing became warm and the grease flowed into the bearing. It was found that the lubrication at the best was very uncertain, the friction often fluctuating greatly.

Y GREASE NO. 5. LOAD ON BEARING, 74.1 lbs. per sq. in.

Time of Day.	Spring Balance				Bearing Temperature °F	Coefficient of Friction ϕ	Remarks
	P_1		P_2				
	lbs.	oz.	lbs.	oz.			
11:33	*7	8			76	.0244	Readings marked * were taken immediately after forcing grease into the bearing.
35	7	9			79	.0276	
36	rev	ersed	mot	or.			
38			*6	9	80	.0244	
39			6	8	80	.0276	
40			6	7	80	.0310	
40			*6	9	81	.0244	
46			6	7½	82	.0293	
47			6	7	82	.0310	
47			*6	11	82	.0210	
57			6	5¼	83	.0396	
57			*6	11½	....	.0201	
	rev	ersed	mot	or.			
12:00	7	11½			....	.0325	
02	7	12½			82	.0350	
02	*7	8			....	.0210	

SECOND TEST AT SAME LOAD, BUT AT HIGHER TEMPERATURES

5:26	7	6½			110	.0178	
26	*7	5½			......	.0146	
29	7	6			118	.0162	
29	*7	5½			......	.0146	
	rev	ersed	mot	or.			
30			6	12	120	.0162	
32			6	12	......	.0162	
32			*6	12½	......	.0146	
40			6	10	160	.0228	
40			*6	10	160	.0228	
	rev	ersed	mot	or.			
42	7	8			164	.0236	
43	7	7½			160	.0220	
46	7	8			158	.0236	
47	8	0			......	.049	Unsteady.
47	*7	7½			......	.0220	
52	*7	10			185	.0260	
53	7	10			190	.0260	
54	7	9¾			......	....	
	rev	ersed	mot	or.			
55			6	10	......	.0260	
55			*6	10	190	.0260	
6:01			6	10	......	....	

It will be noticed that the variation in friction referred to is much more marked at low temperature than at high ones. presumably because the grease flows better when hot

The best results, so far as producing constant and uniform conditions of lubrication are concerned, were obtained when using a grease cup with a plunger actuated by a helical spring so as to give a constant feed. When adjusted to feed grease steadily and uniformly, the coefficient of friction at a given load and temperature remained about constant. With the intermittent feed of the hand operated grease cup, results in this regard were not so good. In many of the tests, where observations were taken immediately after feeding the grease, and at one minute intervals thereafter, the friction was seen to steadily increase, even with the bearing of the form of fig. 4, decreasing again to its former value upon again forcing in grease. This is illustrated by the following abstracts from the original log of tests of Y grease No. 5, shown in the table on page 12.

TABLE NO. 1.

X GREASE, NO. 1 DENSITY.

Series A. Loads, 46 to 148 pounds per square inch. See figs. 5 and 6.
Diameter of journal, 2 5-8"; length, 1 1-2".
Compression grease cup used, with intermittent feed of the lubricant.

Load on bearing, 46 lbs. per sq. in. Surface speed of journal, 730 to 860 feet per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	86	.0675	Room temperature, 84 deg.
2	96	.0520	
3	104	.0440	
4	110	.0380	
5	114	.0410	Motor reversed.
6	119	.0390	
7	122	.0350	
8	125	.0350	Motor reversed.
9	127	.0350	
10	130	.0350	
11	131	.0330	Motor reversed.
12	132	.0320	
13	133	.0330	
14	135	.0300	
15	136	.0306	
16	137	.0324	

Load on bearing, 71.5 lbs. per sq. in. Surface speed of journal, 690 to 850 feet per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	74	.0528	Room temperature, 75 deg.
2	86	.0426	
3	97	.0325	
4	103	.0324	
5	109	.0280	Motor reversed.
6	112	.0280	
7	116	.0282	
8	119	.0250	Motor reversed
9	123	.0244	
10	125	.0244	
11	126	.0244	Motor reversed.
12	127	.0244	
13	129	.0244	
14	131	.0224	Motor reversed.
15	135	.0240	
16	137	.0240	
17	138	.0244	Motor reversed.
18	138	.0228	

Load on bearing, 122 lbs. per sq. in. Surface speed of journal, 745 to 855 ft. per. min

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	71	.0344	Room temperature, 72 deg.
2	88	.0256	
3	101	.0220	
4	109	.0202	
5	113	.0192	Motor reversed.
6	118	.0183	
7	121	.0183	
8	124	.0126	Motor reversed.
9	128	.0154	
10	130	.0154	
11	131	.0160	Motor reversed.
12	133	.0160	
13	134	.0161	
14	137	.0148	Motor reversed.
15	138	.0148	
16	139	.0148	
17	140	.0150	Motor reversed.
18	141	.0150	

Load on bearing, 148 lbs. per sq. inch. Surface speed of journal, 690 to 850 ft. per. min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	74–84	.0310	Room temperature, 77 deg.
2	91–98	.0214	Motor was reversed after each observation.
3	105	.0191	
4	113	.0188	
5	121	.0191	
6	128	.0142	
7	132	.0144	
8	139	.0142	
9	143	.0152	
10	145	.0144	

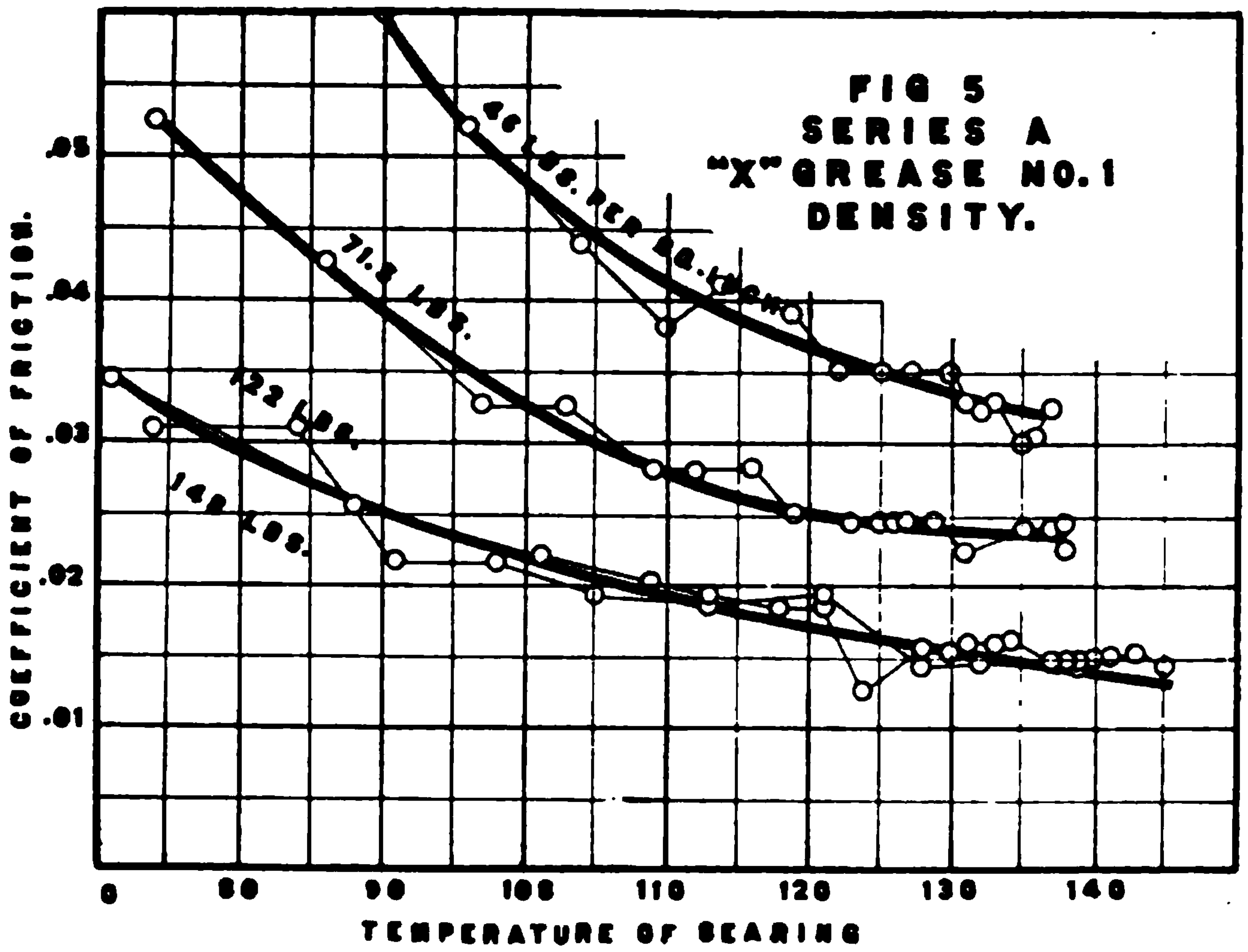


FIG 5
SERIES A
"X" GREASE NO. 1
DENSITY.
COEFFICIENT OF FRICTION.
.05
.04
.03
.02
.01
TEMPERATURE OF BEARING

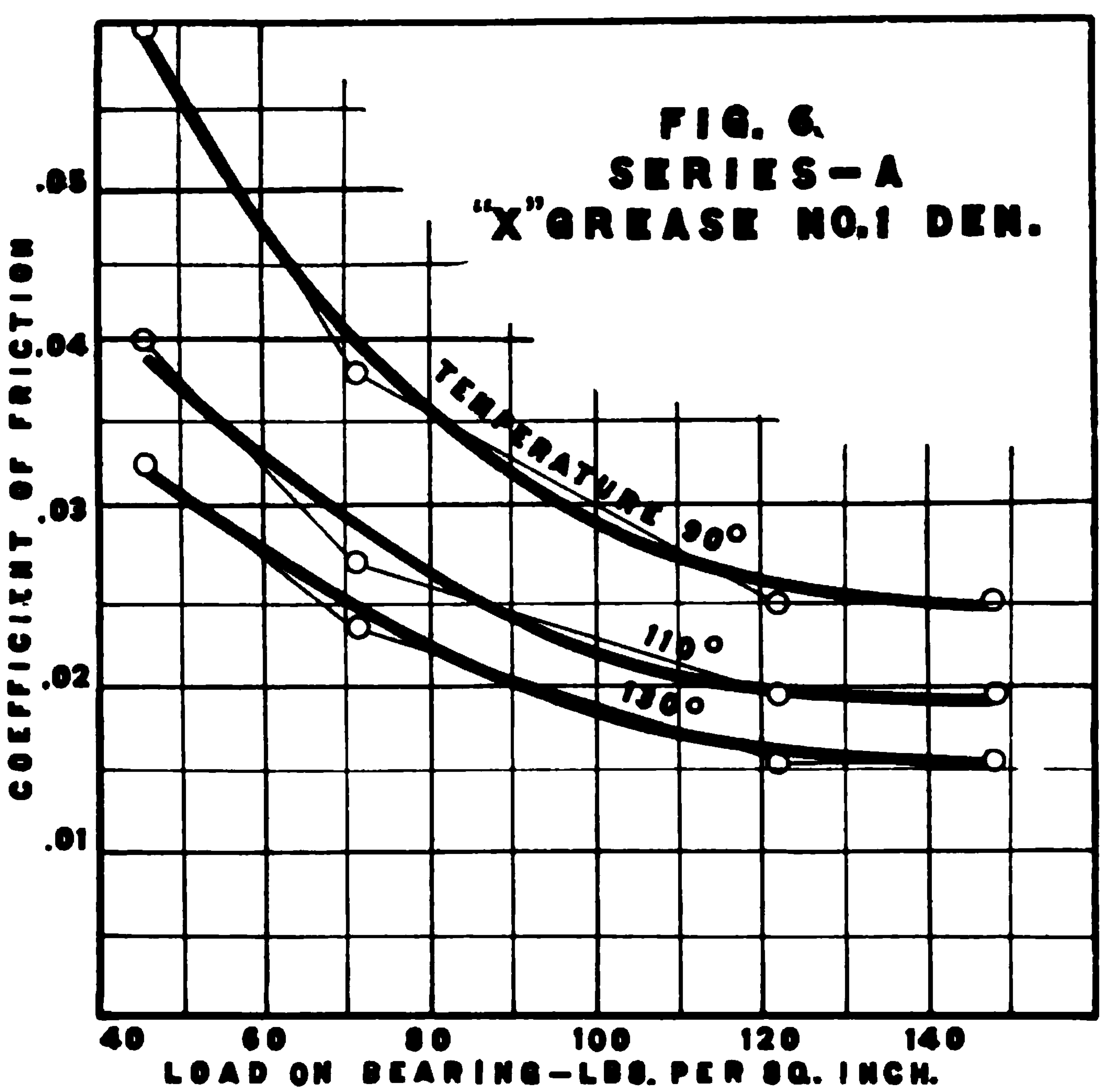


FIG. 6.
SERIES—A
"X" GREASE NO. 1 DEN.
COEFFICIENT OF FRICTION
.05
.04
.03
.02
.01
TEMPERATURE 90°
110°
130°
40
60
80
100
120
140
LOAD ON BEARING—LBS. PER SQ. INCH.

TABLE NO. 2.

X GREASE, NO. 3 DENSITY.

Series A. Loads, 46 to 148 pounds per square inch. See figs. 7 and 8.
Diameter of journal, 2 5-8"; length, 1 1-2".
Compression grease cup used, with intermittent feed of the lubricant.

Load on bearing, 46 lbs. per sq. inch. Surface speed of journal 775 to 860 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	98	.0525	
2	105	.0391	
3	111	.0375	Motor reversed.
4	113	.0350	
5	115	.0350	
6	117	.0343	
7	121	.0327	Motor reversed.
8	124	.0344	
9	126	.0327	Motor reversed.
10	127	.0300	
11	128	.0342	Motor reversed.
12	130	.0310	
13	131	.0346	

Load on bearing, 71.5 lbs. per sq. inch. Surface speed of journal, 750 to 845 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	76	.0495	
2	88	.0385	
3	100	.0334	
4	107	.0313	Motor reversed.
5	111	.0294	
6	115	.0272	
7	117	.0260	Motor reversed.
8	121	.0295	
9	124	.0265	
10	127	.0230	Motor reversed.
11	128	.0232	
12	130	.0230	Motor reversed.
13	131	.0230	
14	132	.0204	
15	134	.0254	Motor reversed.
16	135	.0192	

Load on bearing, 97 lbs. per sq. in. Surface speed of journal 690 to 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	90	.0365	
2	101	.0225	
3	109	.0240	
4	116	.0204	
5	120	.0210	Motor reversed.
6	123	.0217	
7	126	.0202	
8	130	.0210	Motor reversed.
9	135	.0210	
10	140	.0218	
11	139	.0172	Motor reversed.
12	138	.0164	
13	138	.0186	
14	140	.0195	Motor reversed.
15	146	.0115	
16	145	.0165	
17	144	.0172	

Load on bearing, 122 lbs. per sq. in. Surface speed of journal, 580 to 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	74	.0244	
2	86	.0292	
3	97	.0202	
4	105	.0167	
5	110	.0182	Reversed motor.
6	115	.0180	
7	119	.0170	
8	122	.0160	Reversed motor.
9	125	.0160	
10	127	.0143	
11			Reversed motor.
12	132	.0142	
13	135	.0125	Reversed motor.
14	137	.0131	
15	138	.0131	
16	139	.0143	

Load on bearing, 148 lbs. per sq. inch. Surface speed of journal, 690 to 825 ft. per min

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	78	.0304	Motor was reversed at each observation.
2	92	.0267	
3	101	.0232	
4	112	.0167	
5	120	.0155	
6	125	.0167	
7	130	.0135	
8	133	.0132	
9	140	.0129	
10	140	.0152	
11	154	.0122	
12	151	.0133	

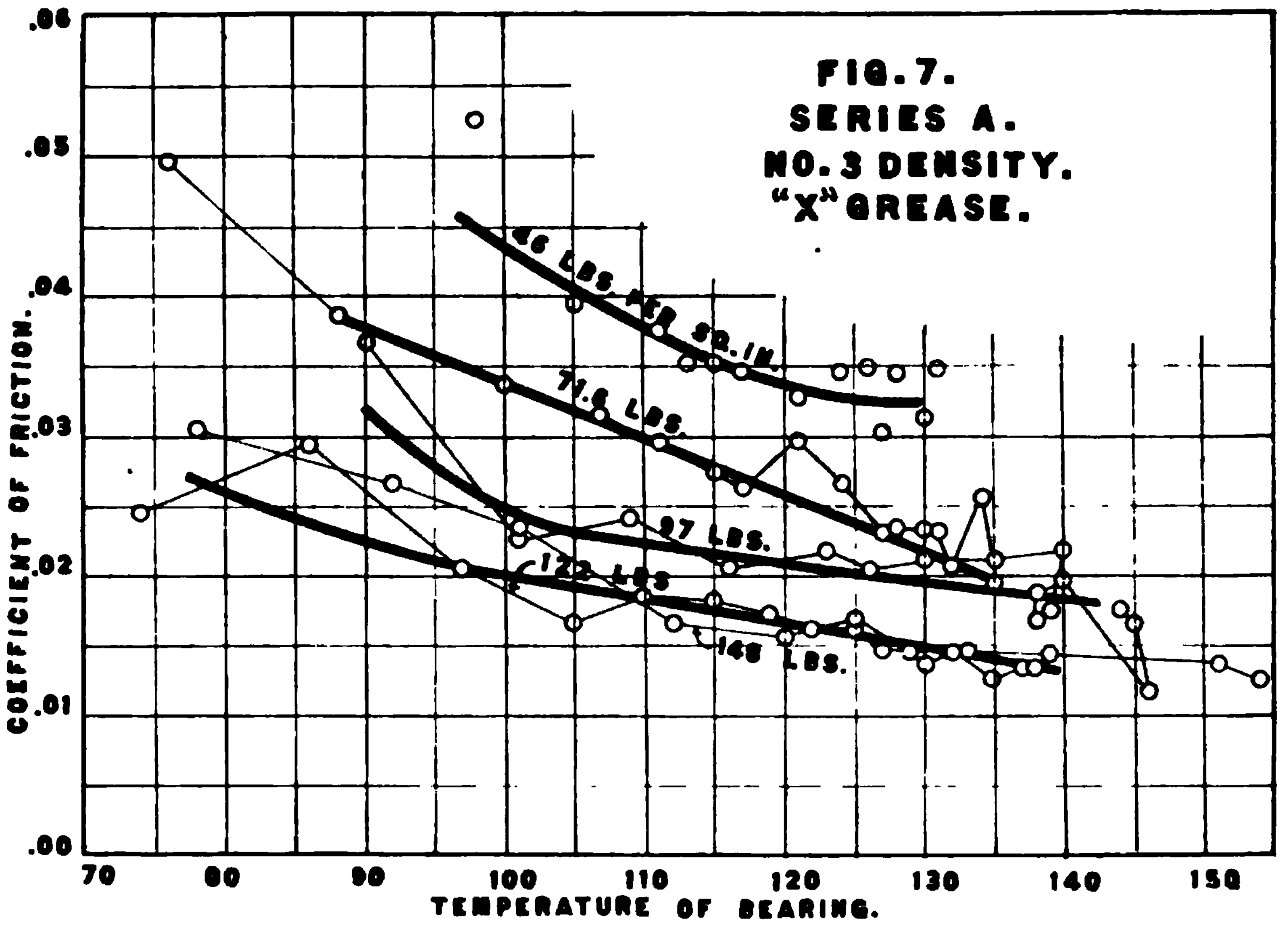


FIG. 7.
SERIES A.
NO. 3 DENSITY.
"X" GREASE.
46 LBS. PER SQ. IN.
71.6 LBS.
97 LBS.
122 LBS
148 LBS.
COEFFICIENT OF FRICTION.
TEMPERATURE OF BEARING.

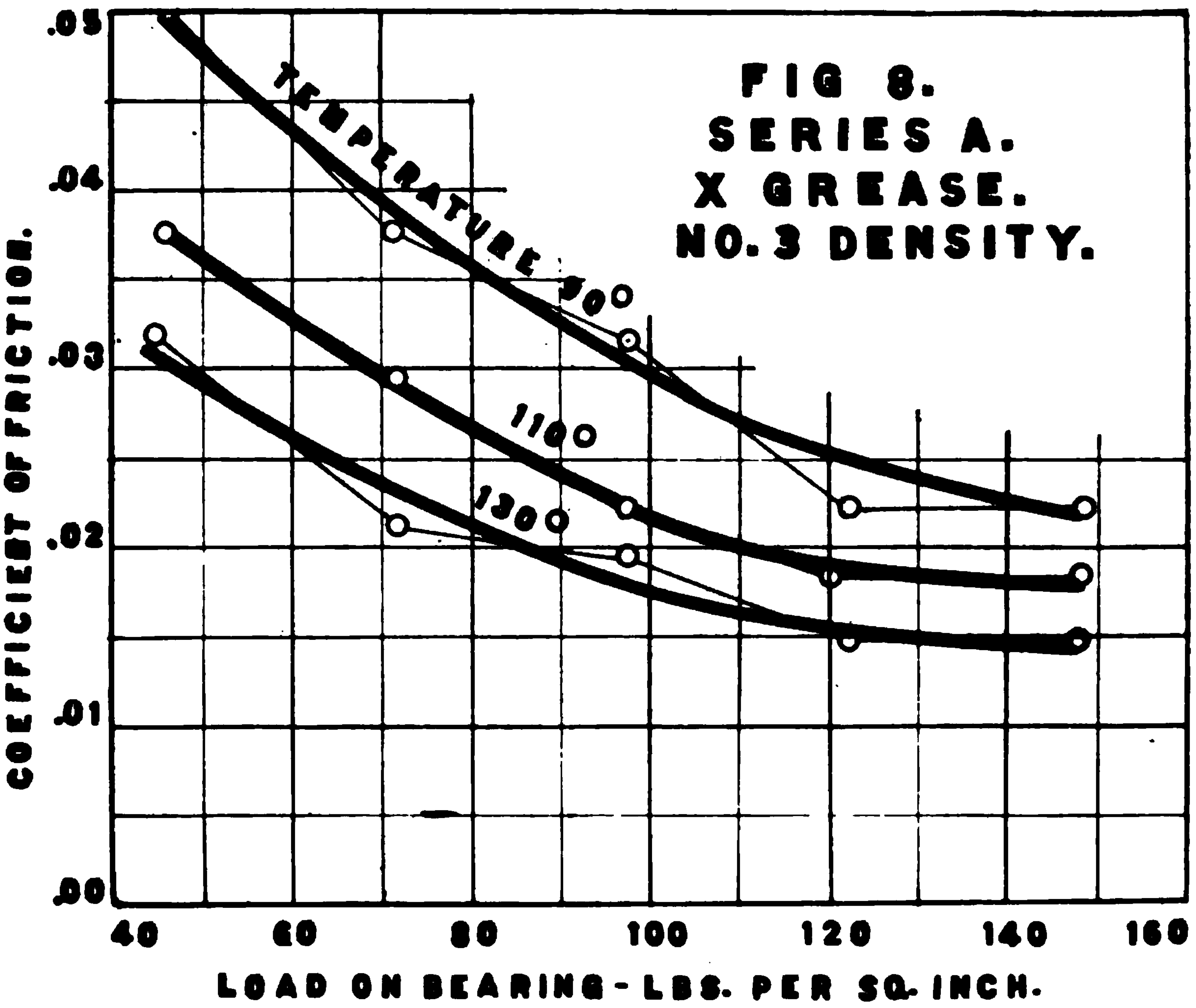


FIG 8.
SERIES A.
X GREASE.
NO. 3 DENSITY.
TEMPERATURE 90°
110°
130°
COEFFICIENT OF FRICTION.
LOAD ON BEARING - LBS. PER SQ. INCH.

TABLE NO. 3.

Y GREASE, NO. 2 DENSITY.

Series A. Loads of 46 to 85 lbs. per sq. inch. See figs. 9 and 10.
Diameter of journal, 2 5-8″; length, 1 1-2″.
Compression grease cup used, with intermittent feed of the lubricant.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 46 lbs. per sq. inch. Surface speed of journal, 800 ft. per min.			
1	70	.0504	
2	80	.0460	
3	82	.0421	
4	90	.0400	
5	99	.0340	
6	123	.0355	
7	140	.0378	
8	180	.0300	
Load on bearing, 72 lbs. per sq. in. Surface speed of journal, 725 to 800 feet per min.			
1	69	.0365	
2	71	.0330	
3	83	.0294	
4	95	.0292	
5	115	.0240	
6	147	.0252	
7	208	.0232	
Load on bearing, 85 lbs. per sq. in. Surface speed of journal, 700 feet per minute.			
1	70	.0350	
2	80	.0282	
3	90	.0254	
4	100	.0247	
5	126	.0183	

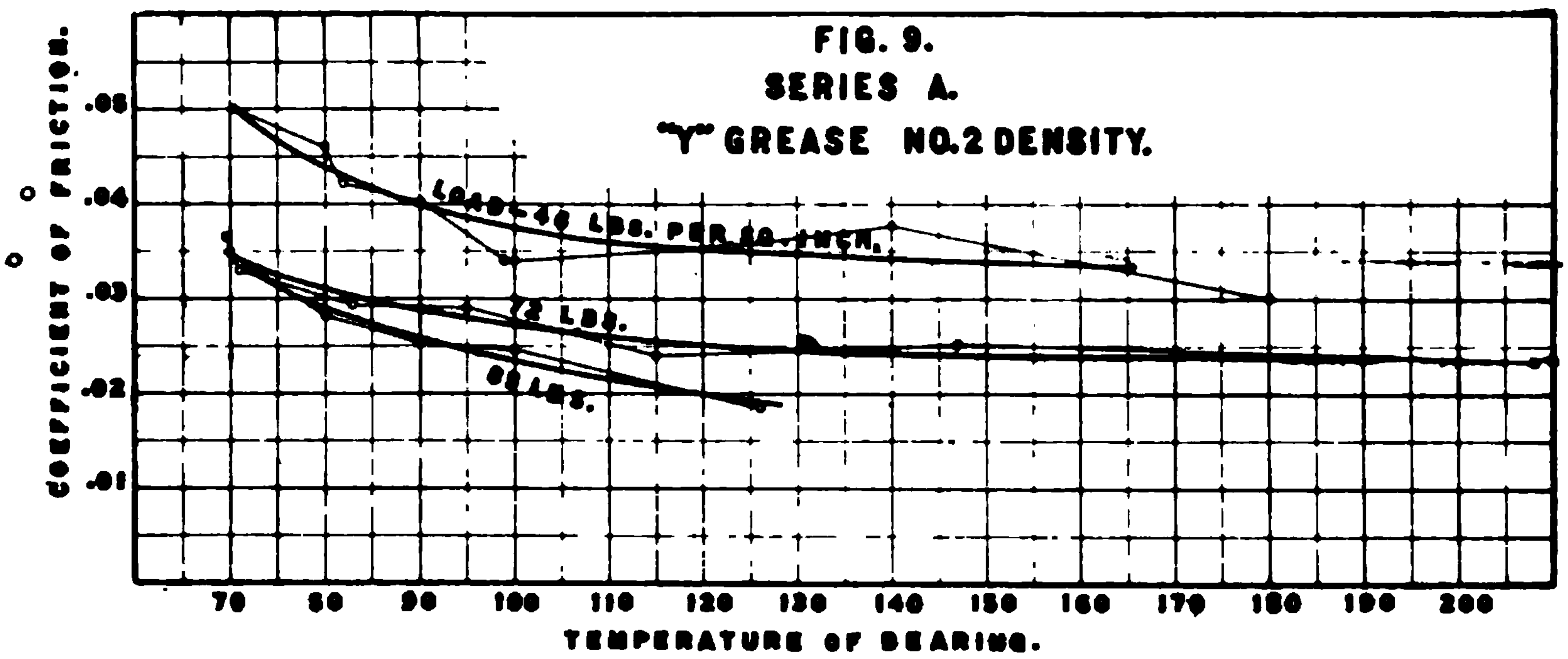


FIG. 9.
SERIES A.
"Y" GREASE NO.2 DENSITY.
LOAD-48 LBS. PER SQ. INCH.
72 LBS.
96 LBS.
COEFFICIENT OF FRICTION.
.05
.04
.03
.02
.01
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TEMPERATURE OF BEARING.

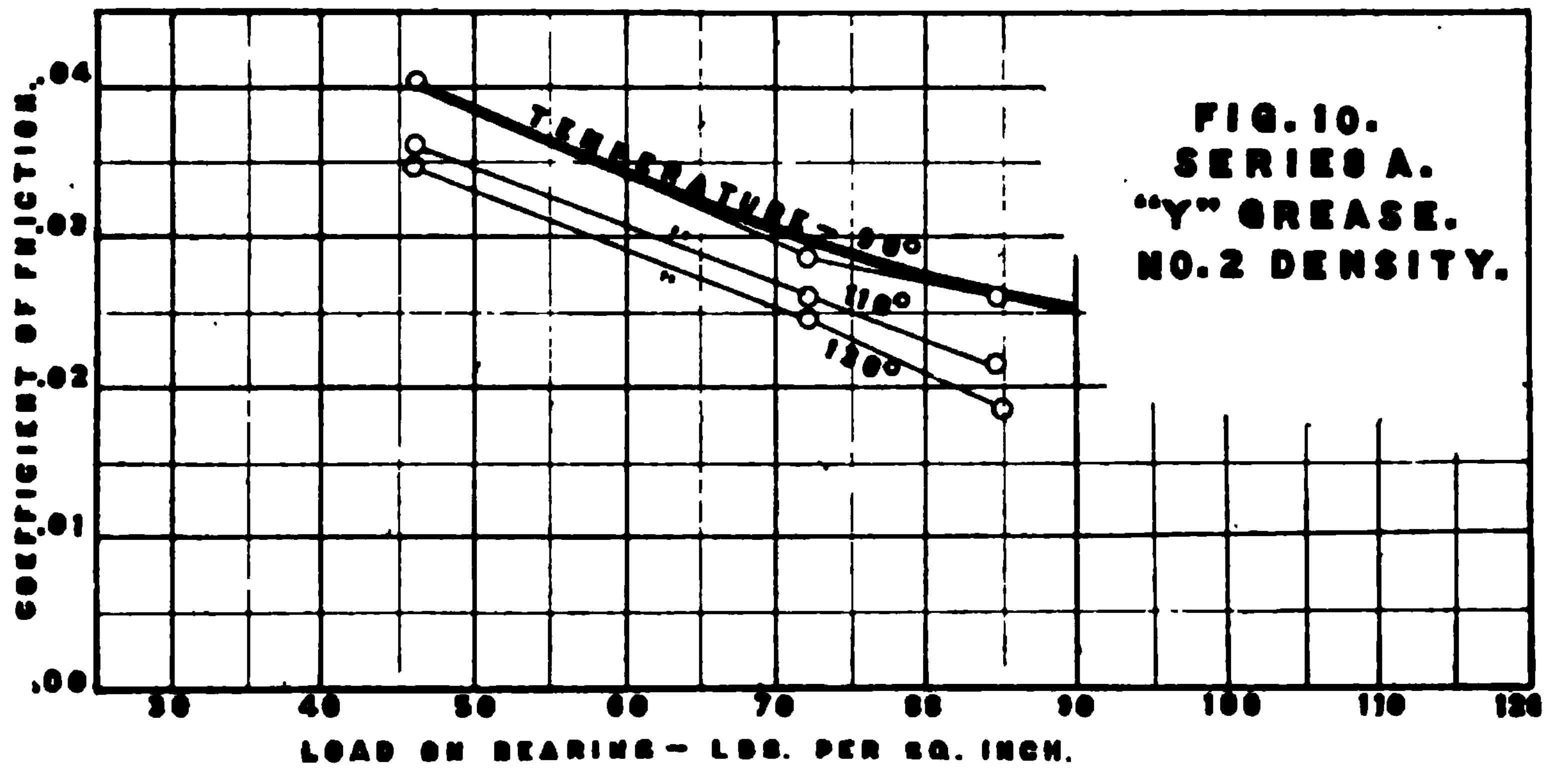


FIG. 10.
SERIES A.
"Y" GREASE.
NO.2 DENSITY.
TEMPERATURE 95°
110°
120°
COEFFICIENT OF FRICTION.
.04
.03
.02
.01
.00
30
40
50
60
70
80
90
100
110
120
LOAD ON BEARING — LBS. PER SQ. INCH.

TABLE NO. 4.

Y GREASE, NO. 1 DENSITY.

Series A. Loads of 34 to 110 lbs. per sq. inch. See figs. 11 and 12.
Diameter of journal, 2 5-8"; length, 1 1-2".
Compression grease cup used, with intermittent feed of the lubricant.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 34 lbs. per sq. inch. Surface speed of journal, 820 to 855 ft. per min.			
1	77	.0479	Ran from 7 to 18 minutes at each temperature, with frequent observations of spring balance. Lubrication was very uniform at all temperatures.
2	92	.0390	
3	112	.0316	
4	145	.0275	
5	180	.0250	
6	209	.0222	
Load on bearing, 46 lbs. per sq. inch. Surface speed of journal, 760 to 870 ft. per min.			
1	78	.0370	Ran 20 to 28 minutes at each temperature.
2	82	.0380	
3	98	.0346	
4	116	.0258	
5	120	.0234	
6	145	.0242	
7	183	.0207	
Second test at load of 46 pounds.			
1	72	.0435	
2	78	.0375	
3	97	.0332	
4	116	.0265	
5	184	.0219	
Load on bearing, 59 lbs. per sq. inch. Surface speed of journal, 690 to 825 ft. per min.			
1	69	.0327	Ran 8 to 16 minutes at each temperature.
2	80	.0310	
3	100	.0275	
4	120	.0220	
5	146	.0204	
6	190	.0177	
7	208	.0190	
Load on bearing. 72 lbs. per sq. inch. Surface speed of journal. 760 to 845 ft. per min.			
1	71	.0348	Ran 9 to 16 minutes at each temperature.
2	82	.0284	
3	114	.0198	
4	143	.0195	
5	182	.0168	
Second test at load of 72 pounds. Surface speed of journal, 730 to 840 feet per minute.			
1	70	.0352	
2	82	.0272	
3	100	.0225	
4	114	.0206	
5	142	.0187	
Load on bearing. 85 lbs. per sq. inch. Surface speed of journal, 810 to 860 feet per min.			
1	70	.0300	Ran 7 to 24 minutes at each temperature.
2	88	.0231	
3	105	.0188	
4	125	.0168	
5	145	.0180	
6	185	.0169	
7	208	.0158	
Load on bearing, 110 lbs. per sq. in. Surface speed of journal, 755 to 825 ft. per min.			
1	80	.0206	Ran 6 to 10 minutes at each temperature.
2	101	.0177	
3	110	.0169	
4	125	.0144	
5	145	.0135	
6	188	.0129	
7	206	.0128	

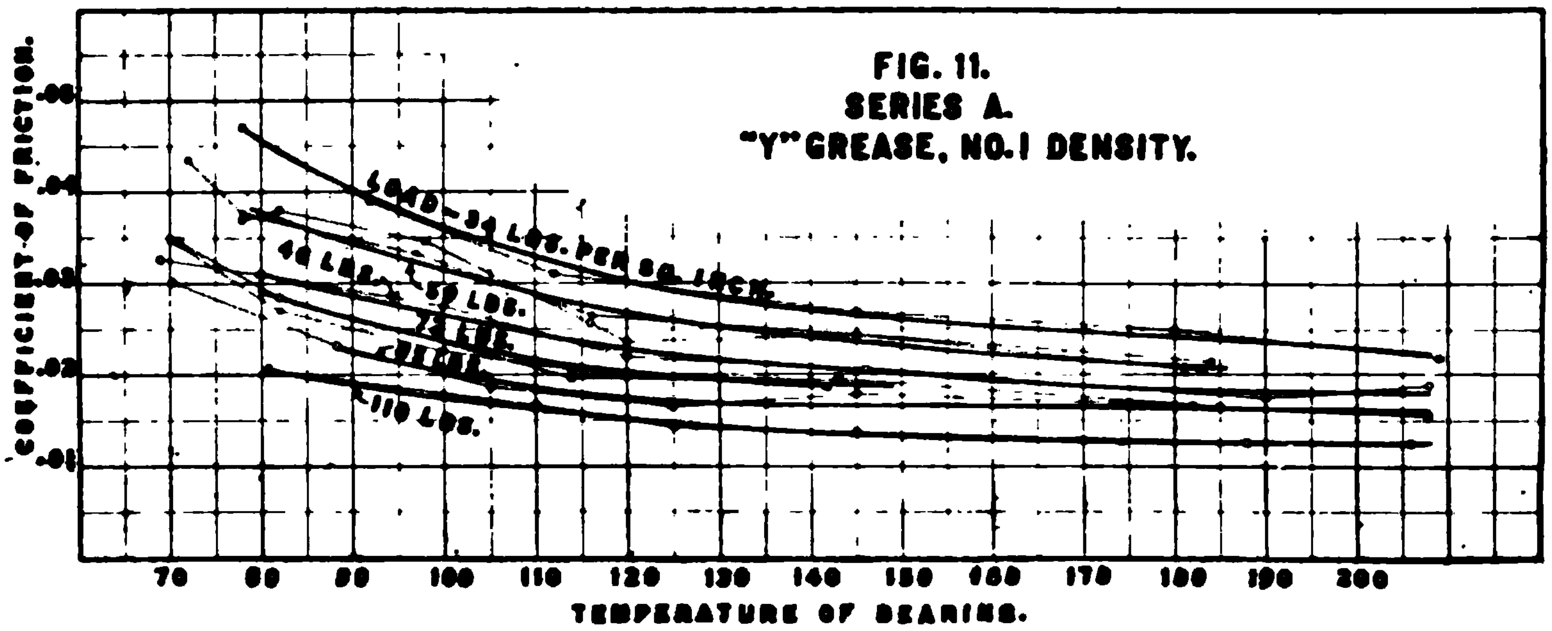


FIG. 11.
SERIES A.
"Y" GREASE, NO. 1 DENSITY.
LOAD—34 LBS. PER SQ. INCH.
46 LBS.
59 LBS.
110 LBS.
COEFFICIENT OF FRICTION.
70 80 90 100 110 120 130 140 150 160 170 180 190 200
TEMPERATURE OF BEARING.

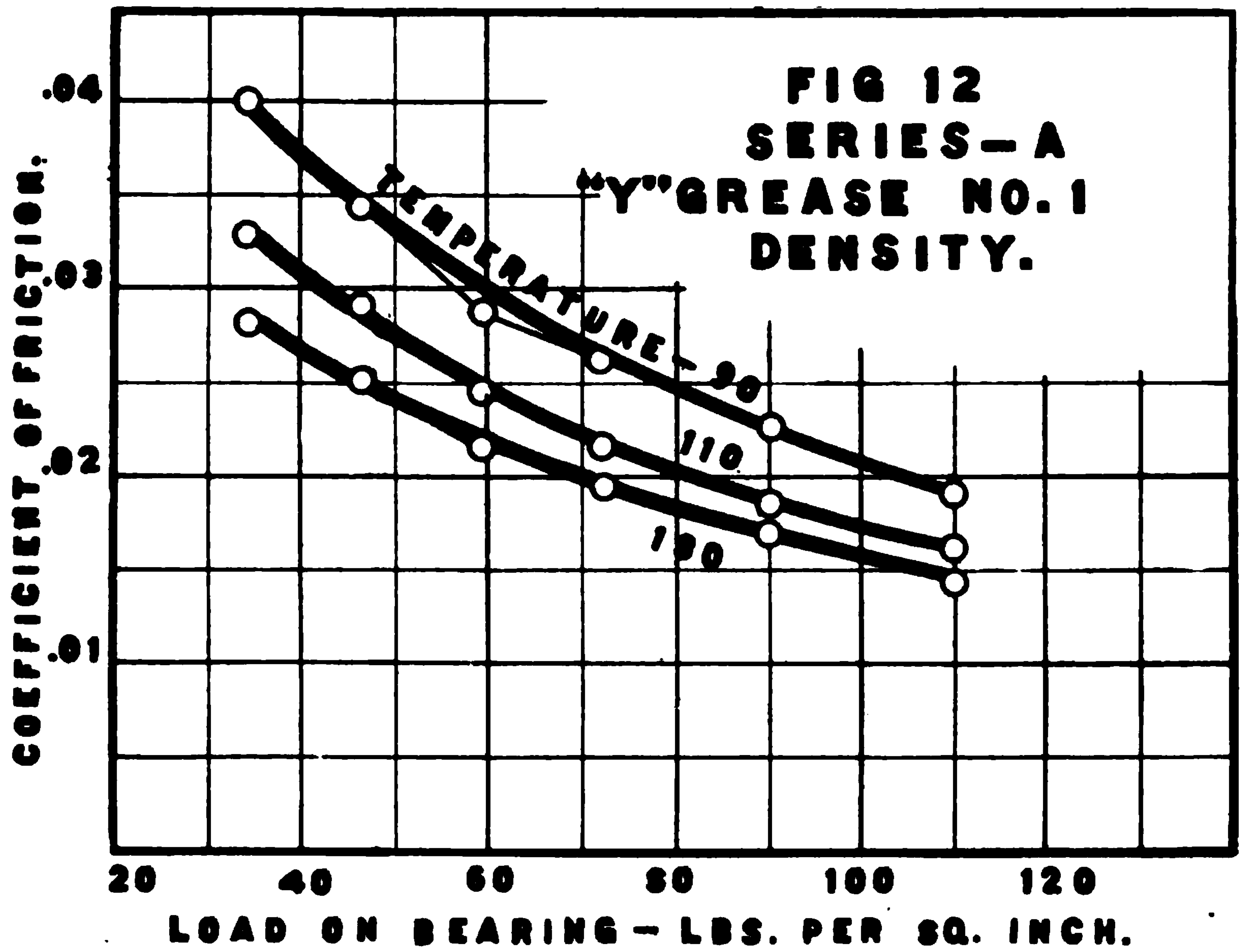


FIG 12
SERIES—A
"Y" GREASE NO. 1
DENSITY.
TEMPERATURE—90
110
130
COEFFICIENT OF FRICTION.
.04
.03
.02
.01
20 40 60 80 100 120
LOAD ON BEARING—LBS. PER SQ. INCH.

TABLE NO. 5. ENGINE OIL

Series A. Loads of 20 to 174 pounds per sq. inch. See figs. 13 and 14.
Diameter of bearing 2 5-8″; length 1 1-2″.
Tests of this oil were for the purpose of comparing oil with grease under the same conditions.

Load on bearing, 20 lbs. per sq. in. Surface speed of journal, 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	79	.0630	Room temperature, 79 deg.
2	82	.0541	Motor was reversed at each observation.
3	87	.0470	
4	90	.0455	
5	92	.0435	
6	96	.0405	
7	100	.0399	
8	105	.0362	
9	108	.0344	
10	109	.0389	
11	110	.0380	
12	111	.0330	
13	111	.0330	
14	111	.0330	

Load on bearing, 46 lbs. per sq. inch. Surface speed of journal 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	88	.0292	Room temperature, 90 deg.
2	93	.0236	Motor was reversed at each observation.
3	98	.0222	
4	101	.0206	
5	104	.0200	
6	106	.0198	
7	108	.0186	
8	109	.0186	
9	111	.0182	
10	112	.0190	
11	114	.0176	
12	115	.0178	
13	116	.0178	
14	117	.0178	
15	118	.0176	
16	...	.0178	
17	119	.0176	
18	120	.0176	

Load on bearing, 71.5 lbs. per sq. in. Surface speed of journal, 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	81	.0234	Motor was reversed at each observation.
2	86	.0209	
3	92	.0173	
4	96	.0170	
5	102	.0170	
6	107	.0146	
7	109	.0142	
8	110	.0142	
9	111	.0135	
10	112	.0135	
11	112	.0130	
12	113	.0130	
13	113	.0136	
14	115	.0136	
15	115	.0137	
16	116	.0129	

Load on bearing, 97 lbs. per sq. in. Surface speed of journal 690 to 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	89	.0138	Room temperature, 90 deg.
2	96	.0137	Motor was reversed at each observation.
3	101	.0133	
4	107	.0129	
5	107	.0123	
6	111	.0121	
7	114	.0119	
8	116	.0120	
9	118	.0120	
10	119	.0120	
11	120	.0120	
12	122	.0119	
13	123	.0119	
14	124	.0117	
15	...	.0121	
16	127	.0117	
17	127	.0105	
18	128	.0105	
19	128	.0105	
20	129	.0104	
21	129	.0105	

TABLE NO. 5. ENGINE OIL—Continued

Number	Bearing Temperature, Degrees F	Coefficient of Friction	Remarks
Load on bearing, 122 lbs. per sq. in. Surface speed of journal, 825 ft. per min.			
1	75	.0196	Room temperature, 77 deg.
2	83	.0144	
3	89	.0136	
4	94	.0099	
5	98	.0126	Motor reversed.
6	102	.0113	
7	104	.0108	
8	...	.0113	Motor reversed.
9	106	.0107	
10	108	.0099	
11	110	.0099	
12	...	.0095	Motor reversed.
13	111	.0092	
14	...	.0099	
15	113	.0107	
16	...	.0077	Motor reversed.
17	115	.0101	
Same load and speed: second test.			
1	81	.0151	
2	87	.0143	Motor reversed.
3	95	.0131	Motor reversed.
4	101	.0114	Motor reversed.
5	104	.0109	Motor reversed.
6	106	.0109	
7	109	.0110	Motor reversed.
8	111	.0108	Motor reversed.
9	113	.0108	
10	115	.0109	Motor reversed.
11	116	.0107	Motor reversed.
12	118	.0106	
13	119	.0106	Motor reversed.
14	121	.0095	
15	123	.0091	Motor reversed.
16	124	.0098	Motor reversed.
17	124	.0098	
18	...	.0096	

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 148 lbs. per sq. in. Surfacespeed of journal, 825 ft. per min.			
1	75	.0172	Room temperature, 76 deg.
2	82	.0142	Motor was reversed at each observation.
3	90	.0120	
4	96	.0108	
5	101	.0108	
6	105	.0113	
7	110	.0121	
8	113	.0105	
9	114	.0094	
10	116	.0083	
11	118	.0082	
12	120	.0082	
Load on bearing, 174 lbs. per sq. in. Surface speed of journal, 755 to 825 ft. per min.			
1	84	.0134	Room temperature, 80 deg
2	91	.0109	Motor was reversed at each observation.
3	96	.0100	
4	100	.0101	
5	106	.0101	
6	111	.0098	
7	114	.0082	
8	116	.0061	
9	117	.0060	
10	119	.0061	
11	120	.0060	
12	121	.0059	

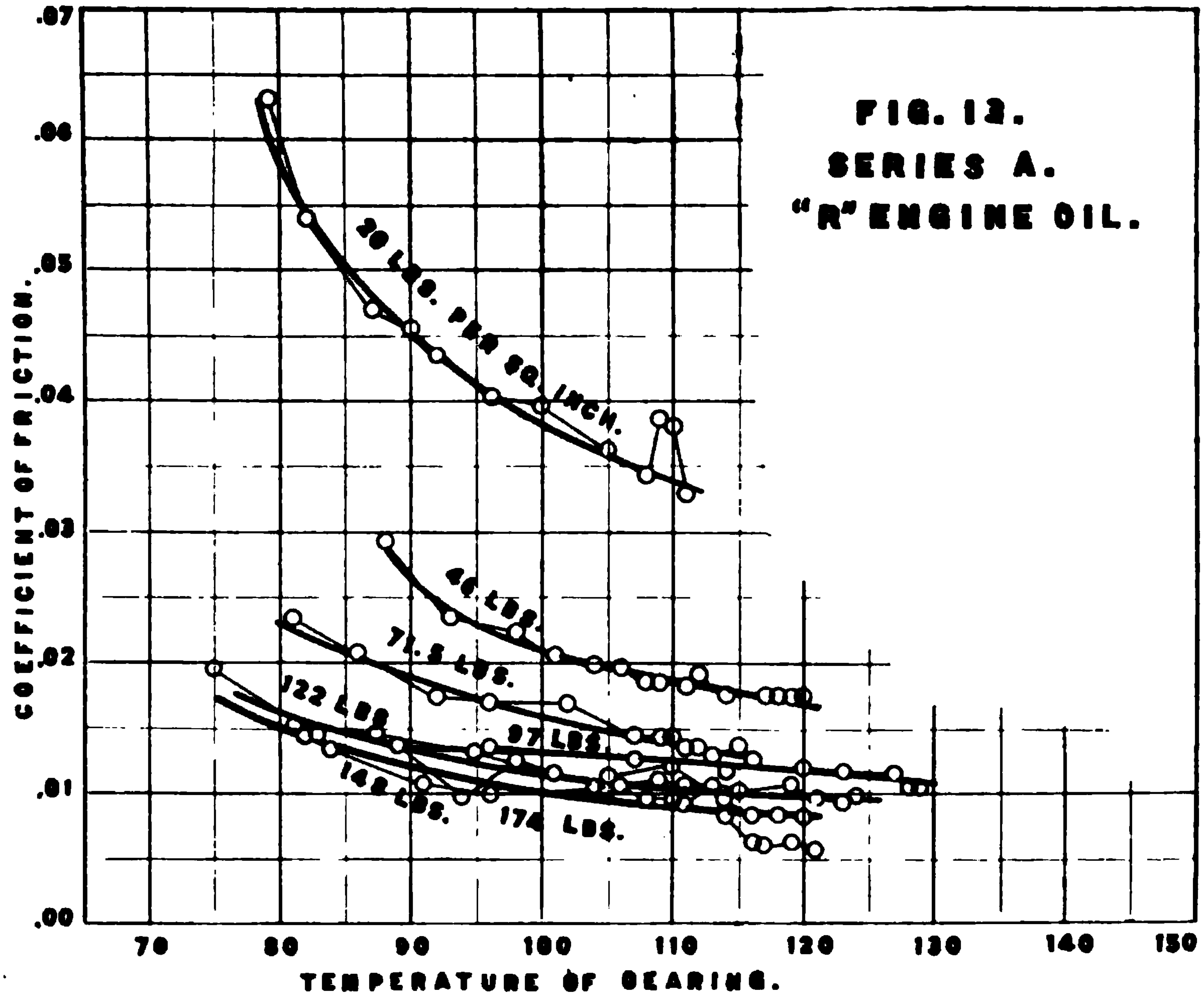


FIG. 13.
SERIES A.
"R" ENGINE OIL.
20 LBS. PER SQ. INCH.
46 LBS.
71.5 LBS.
122 LBS.
97 LBS.
148 LBS.
174 LBS.
COEFFICIENT OF FRICTION.
.07
.06
.05
.04
.03
.02
.01
.00
70
80
90
100
110
120
130
140
150
TEMPERATURE OF BEARING.

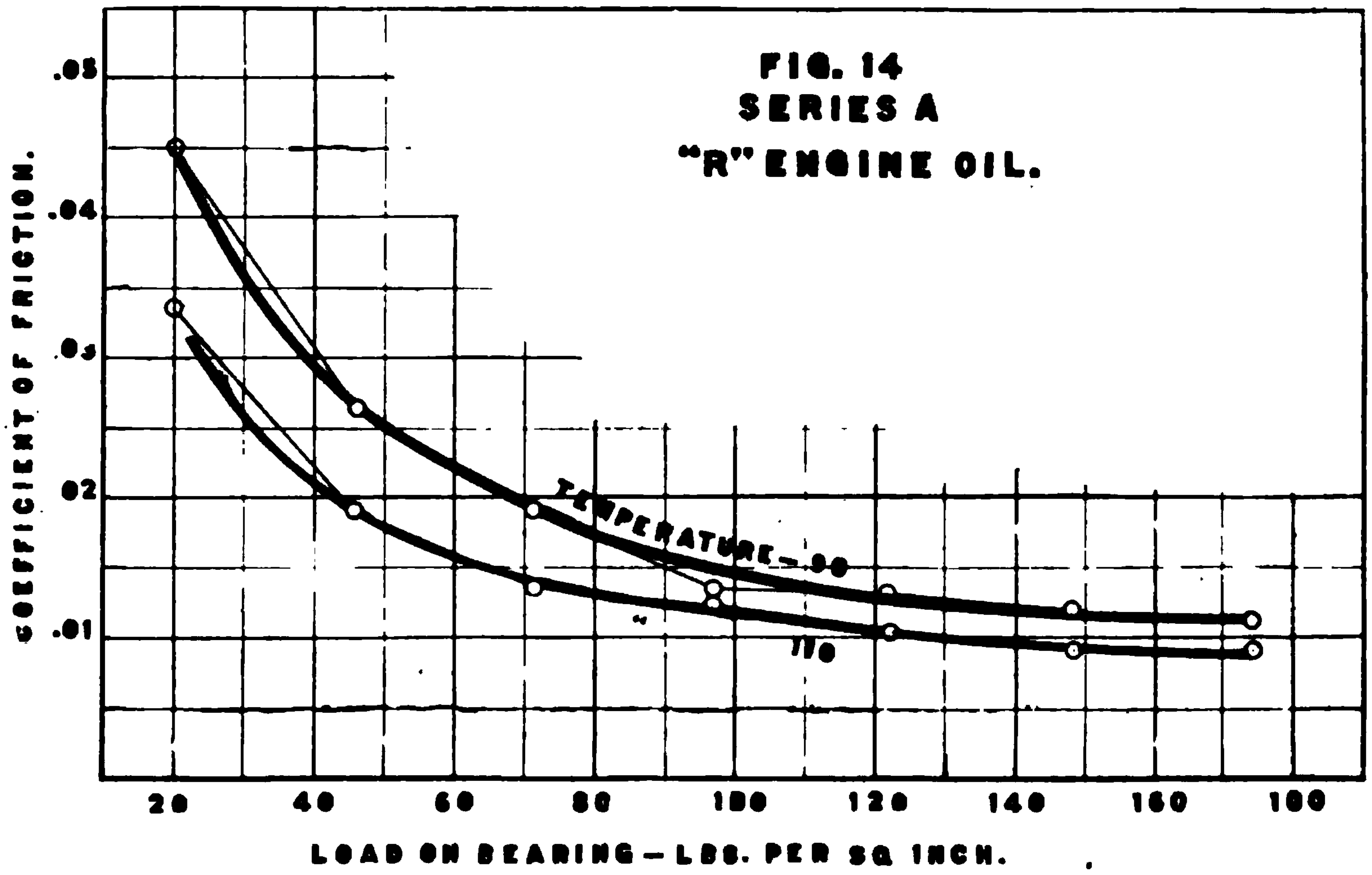


FIG. 14
SERIES A
"R" ENGINE OIL.
TEMPERATURE—90
110
COEFFICIENT OF FRICTION.
.05
.04
.03
.02
.01
20
40
60
80
100
120
140
160
180
LOAD ON BEARING—LBS. PER SQ. INCH.

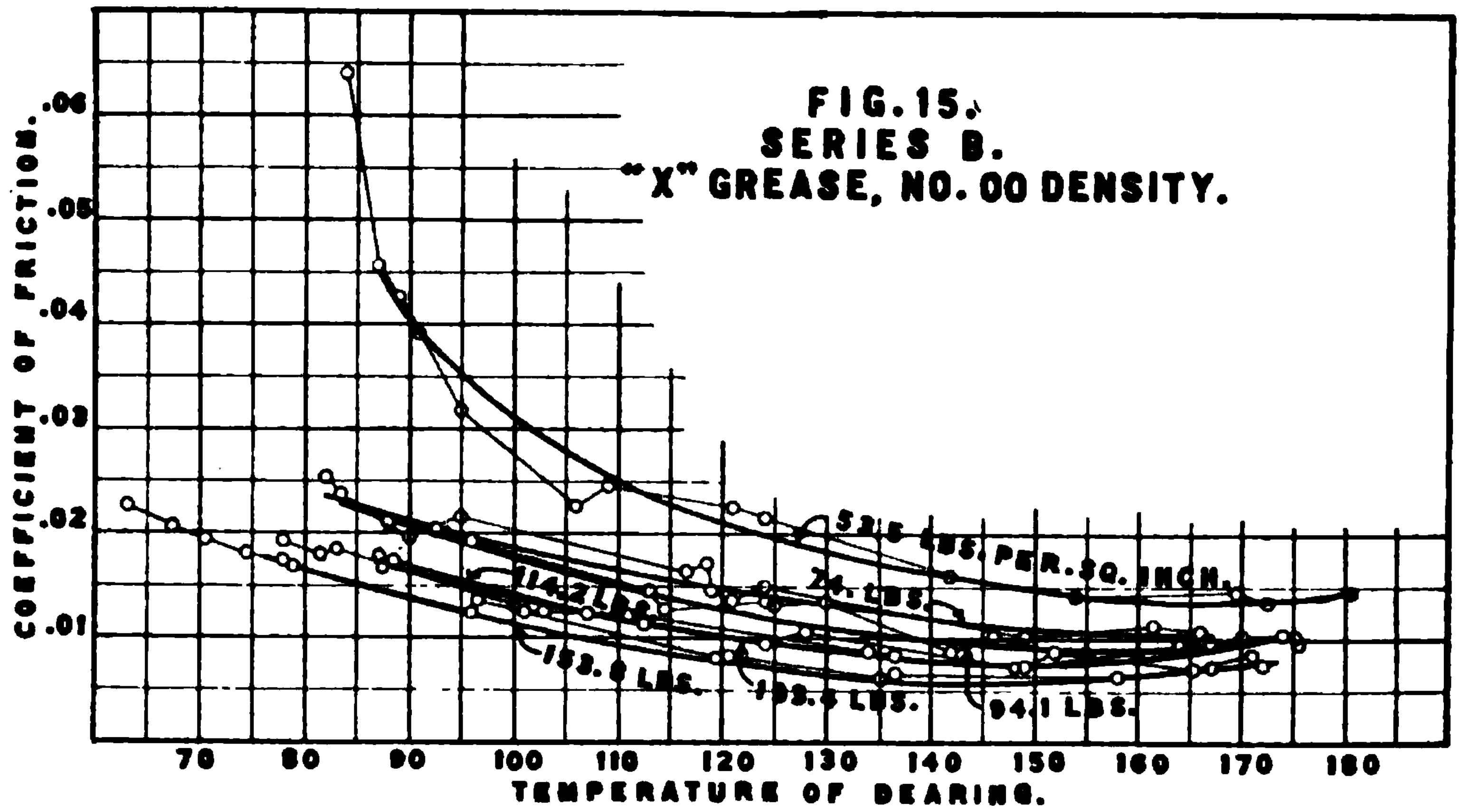


FIG. 15.
SERIES B.
"X" GREASE, NO. 00 DENSITY.
COEFFICIENT OF FRICTION.
TEMPERATURE OF BEARING.
52.5 LBS. PER. SQ. INCH.
74. LBS.
114.2 LBS.
153.8 LBS.
133.4 LBS.
94.1 LBS.
.06
.05
.04
.03
.02
.01
70
80
90
100
110
120
130
140
150
160
170
180

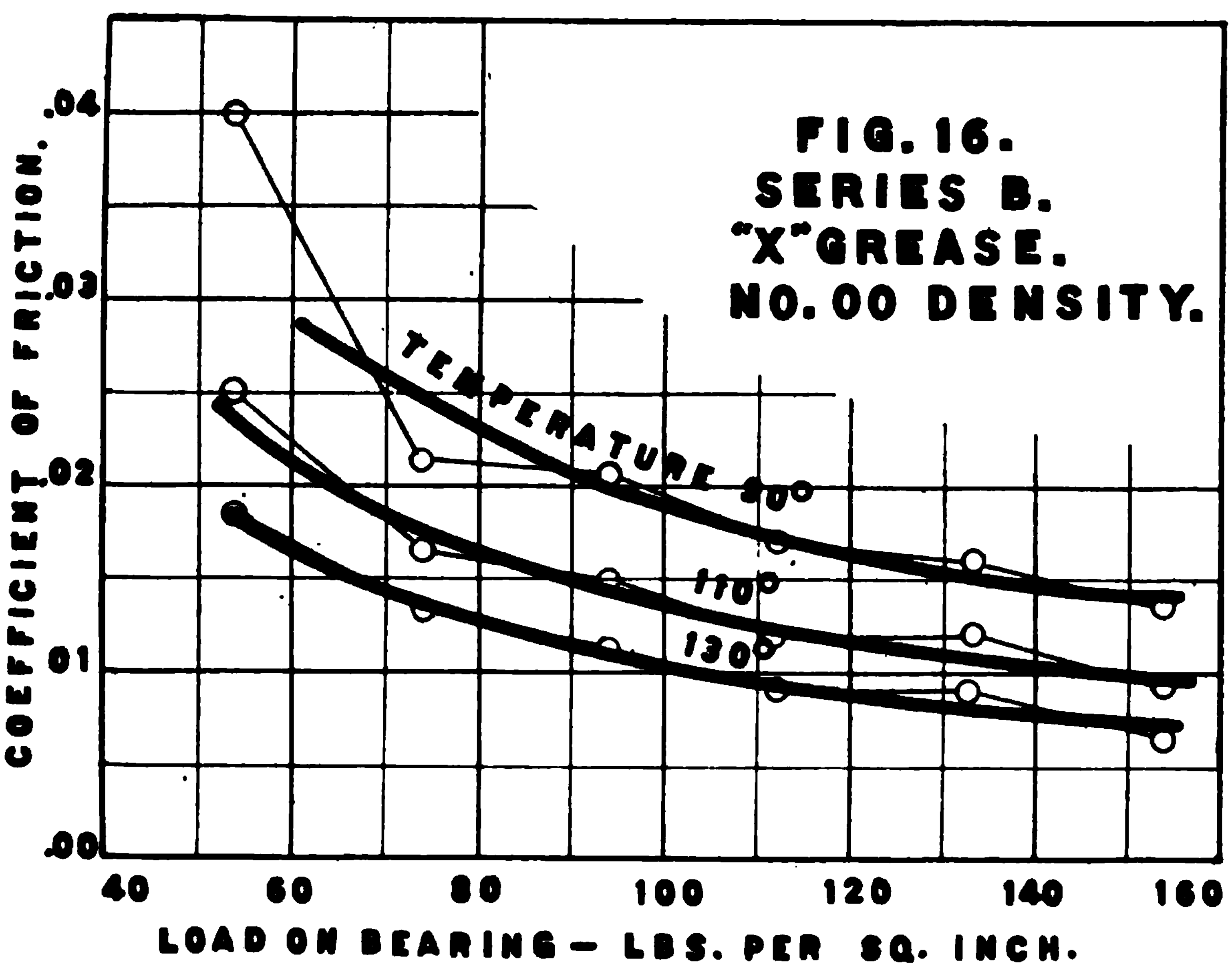


FIG. 16.
SERIES B.
"X" GREASE.
NO. 00 DENSITY.
COEFFICIENT OF FRICTION.
LOAD ON BEARING — LBS. PER SQ. INCH.
TEMPERATURE 90°
110°
130°
.04
.03
.02
.01
.00
40
60
80
100
120
140
160

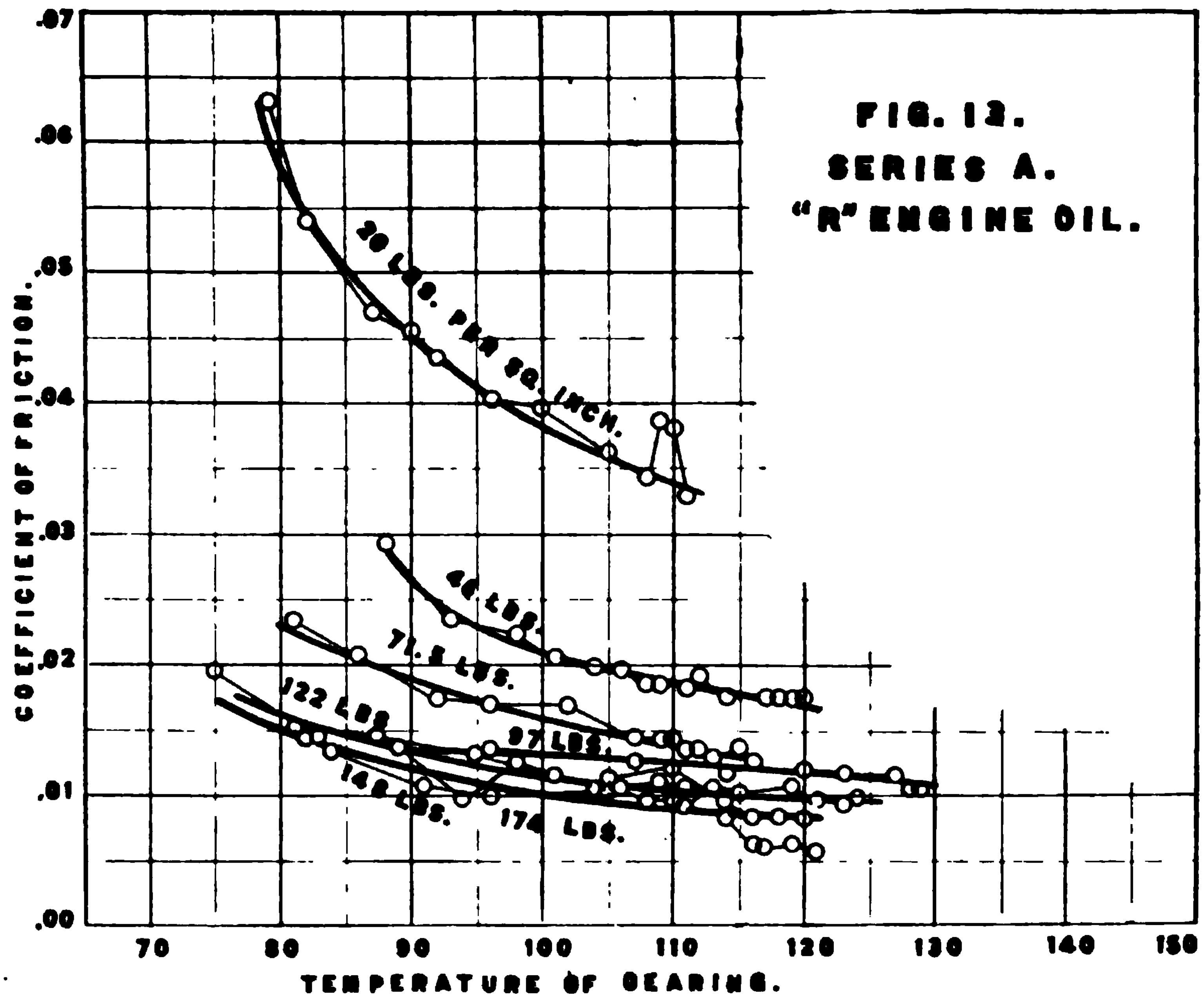


FIG. 13.
SERIES A.
"R" ENGINE OIL.
30 LBS. PER SQ. INCH.
46 LBS.
71.5 LBS.
122 LBS.
97 LBS.
148 LBS.
174 LBS.
COEFFICIENT OF FRICTION.
.07
.06
.05
.04
.03
.02
.01
.00
70
80
90
100
110
120
130
140
150
TEMPERATURE OF BEARING.

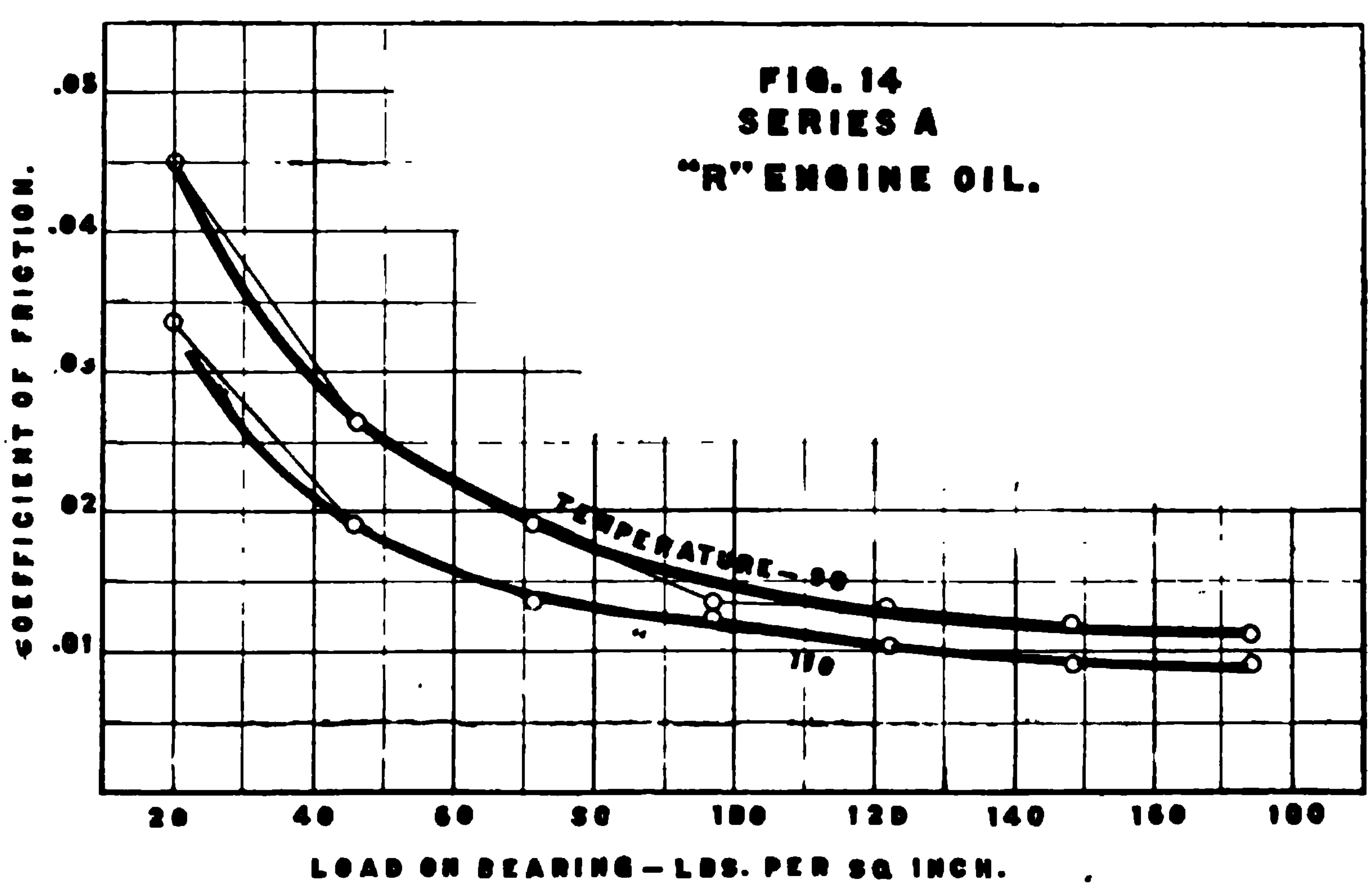


FIG. 14
SERIES A
"R" ENGINE OIL.
TEMPERATURE—90
110
COEFFICIENT OF FRICTION.
.05
.04
.03
.02
.01
20
40
60
80
100
120
140
160
180
LOAD ON BEARING—LBS. PER SQ. INCH.

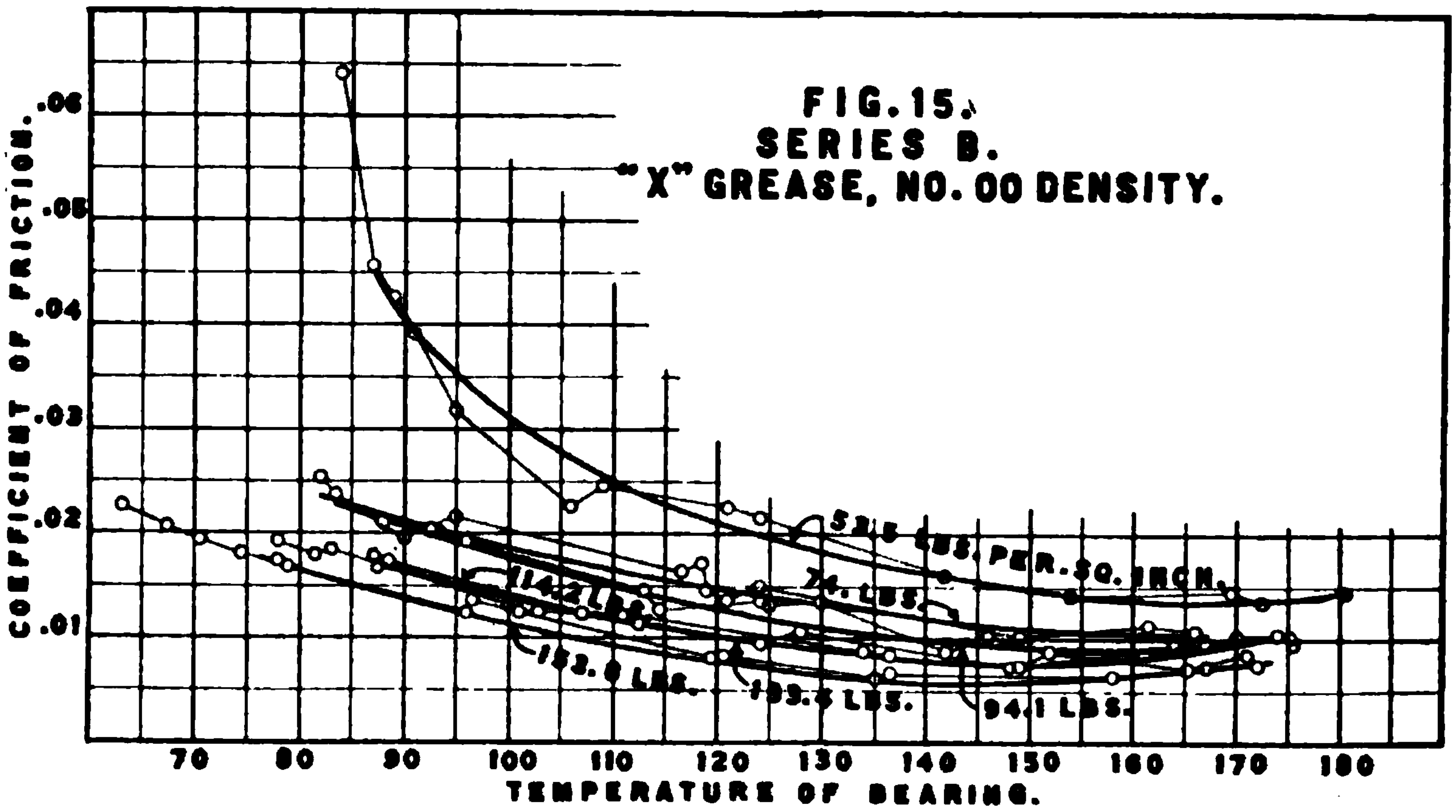


FIG. 15.
SERIES B.
"X" GREASE, NO. 00 DENSITY.
52.5 LBS. PER SQ. INCH.
74. LBS.
114.2 LBS.
153.8 LBS.
133.5 LBS.
94.1 LBS.
COEFFICIENT OF FRICTION.
.06
.05
.04
.03
.02
.01
70
80
90
100
110
120
130
140
150
160
170
180
TEMPERATURE OF BEARING.

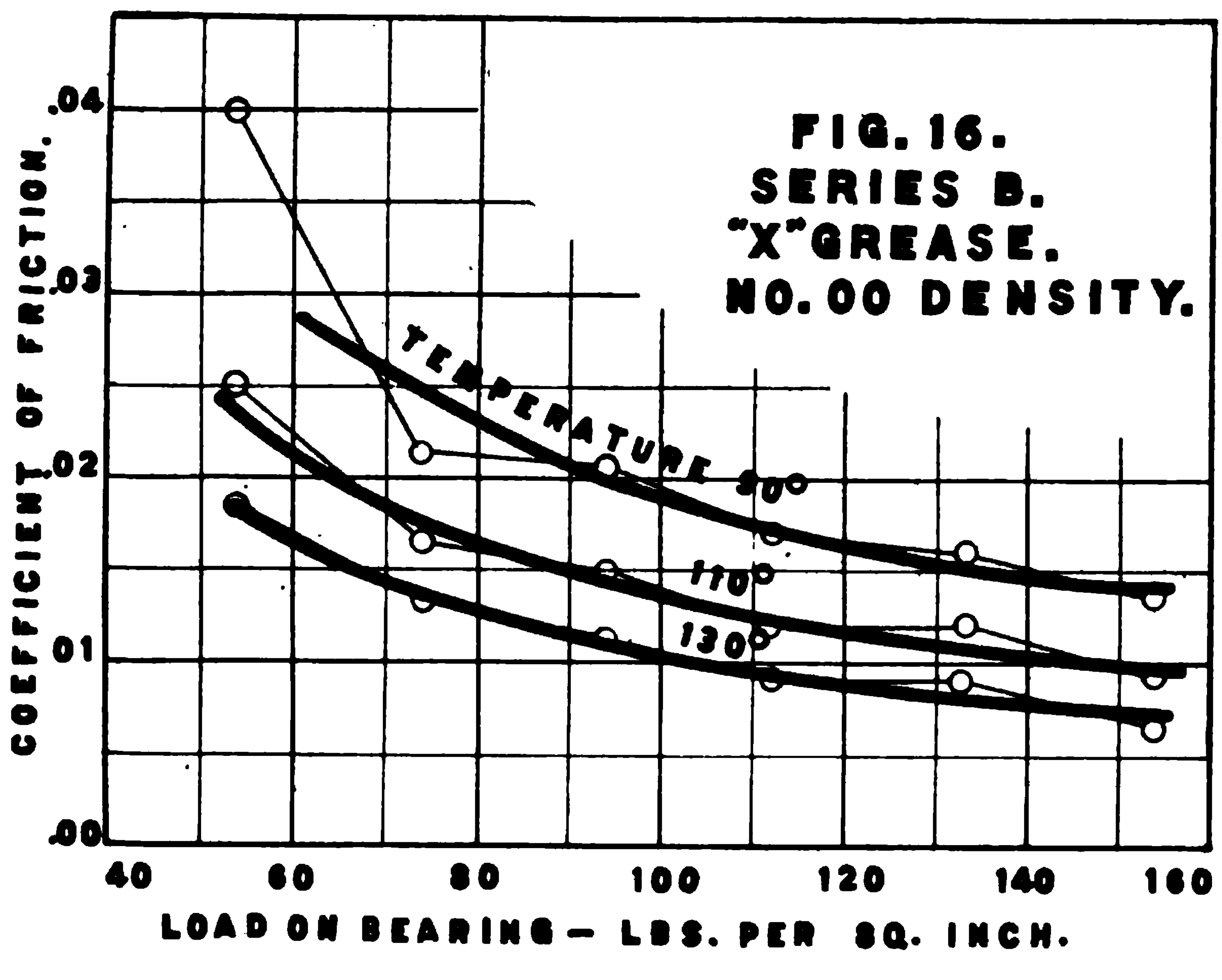


FIG. 16.
SERIES B.
"X" GREASE.
NO. 00 DENSITY.
TEMPERATURE 90°
110°
130°
COEFFICIENT OF FRICTION.
.04
.03
.02
.01
.00
40
60
80
100
120
140
160
LOAD ON BEARING — LBS. PER SQ. INCH.

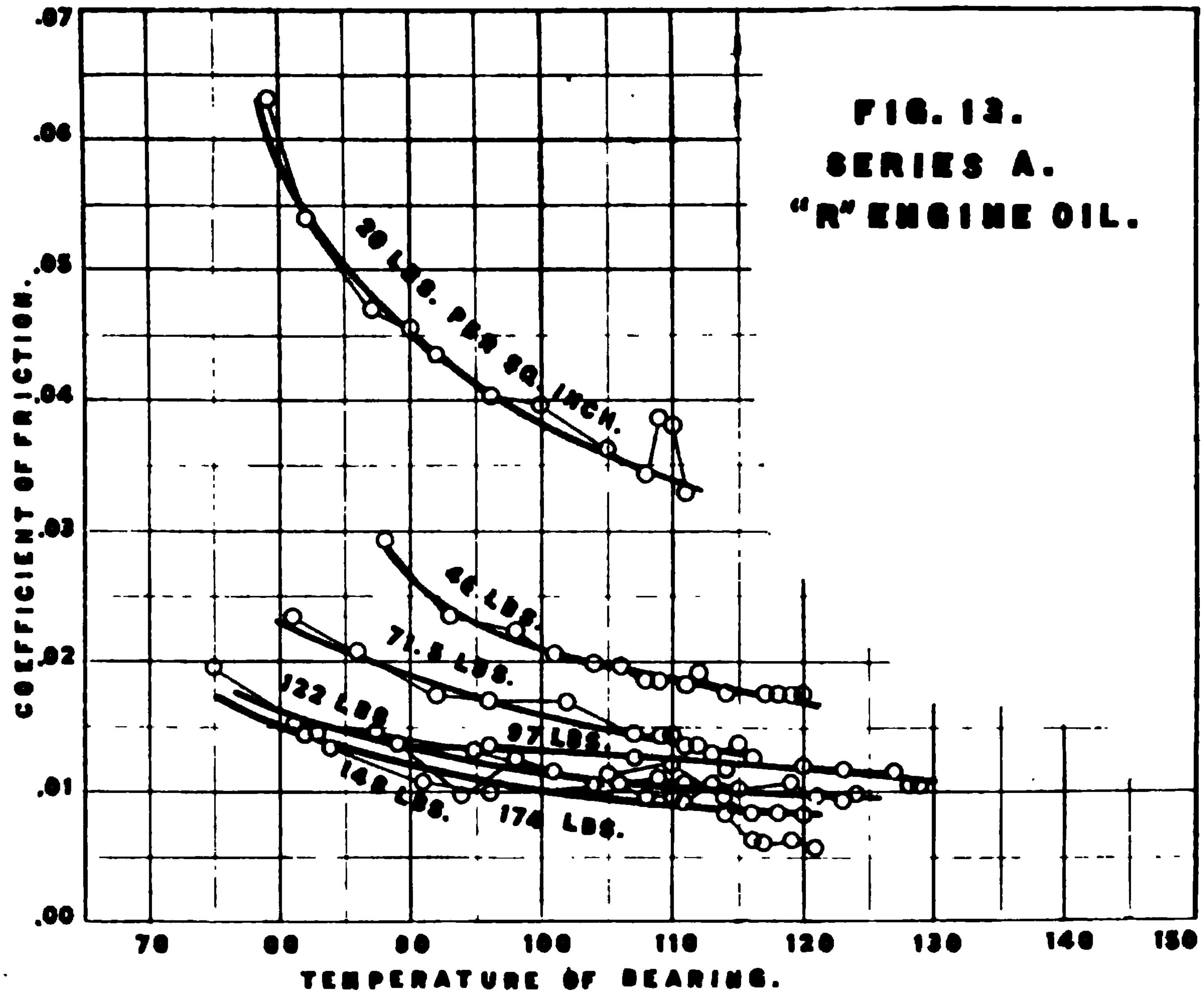


FIG. 13.
SERIES A.
"R" ENGINE OIL.
COEFFICIENT OF FRICTION.
TEMPERATURE OF BEARING.
.07
.06
.05
.04
.03
.02
.01
.00
70
80
90
100
110
120
130
140
150
20 LBS. PER SQ. INCH.
46 LBS.
71.5 LBS.
97 LBS.
122 LBS.
148 LBS.
174 LBS.

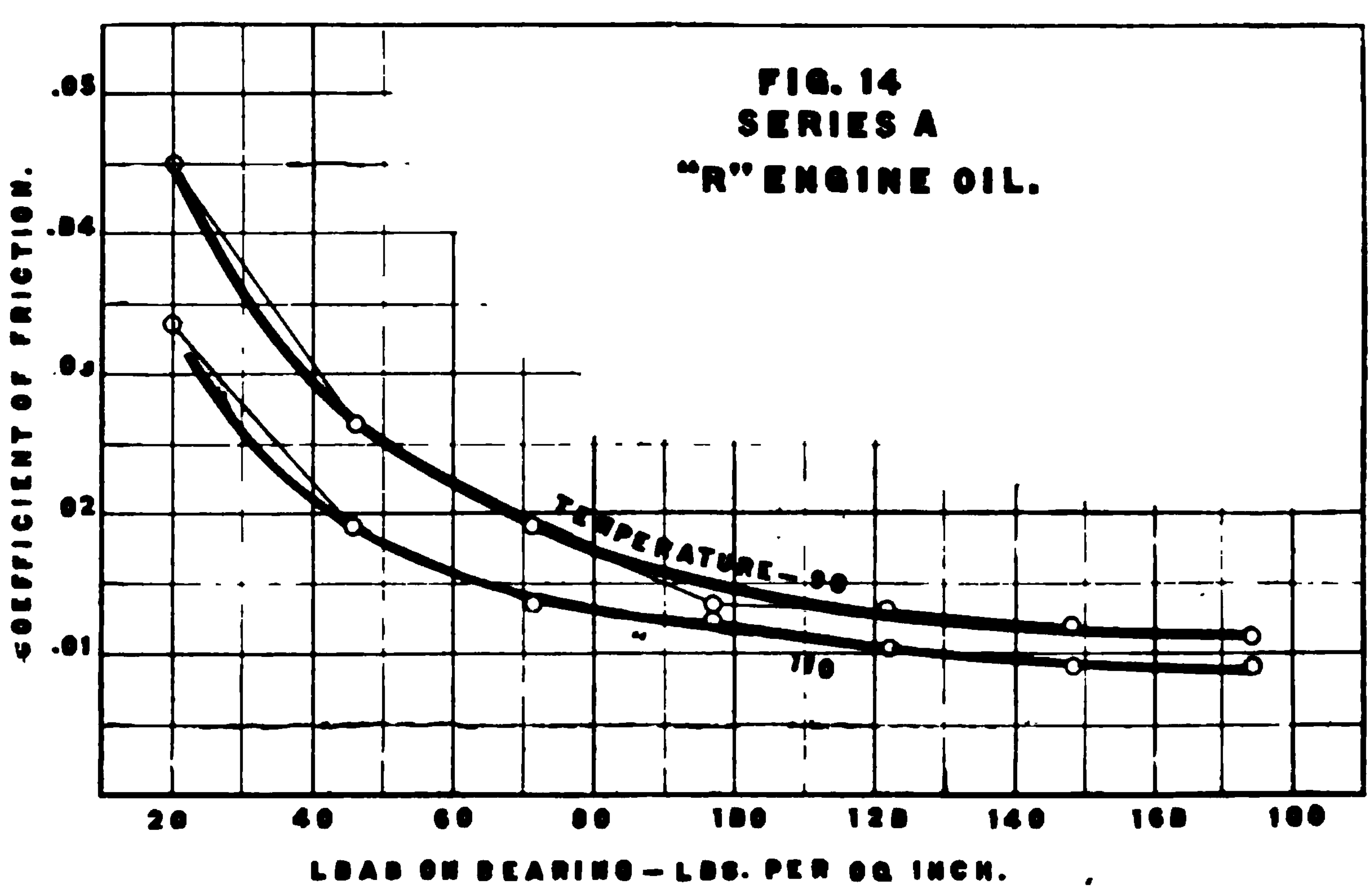


FIG. 14
SERIES A
"R" ENGINE OIL.
COEFFICIENT OF FRICTION.
LOAD ON BEARING—LBS. PER SQ. INCH.
.05
.04
.03
.02
.01
20
40
60
80
100
120
140
160
180
TEMPERATURE—90
110

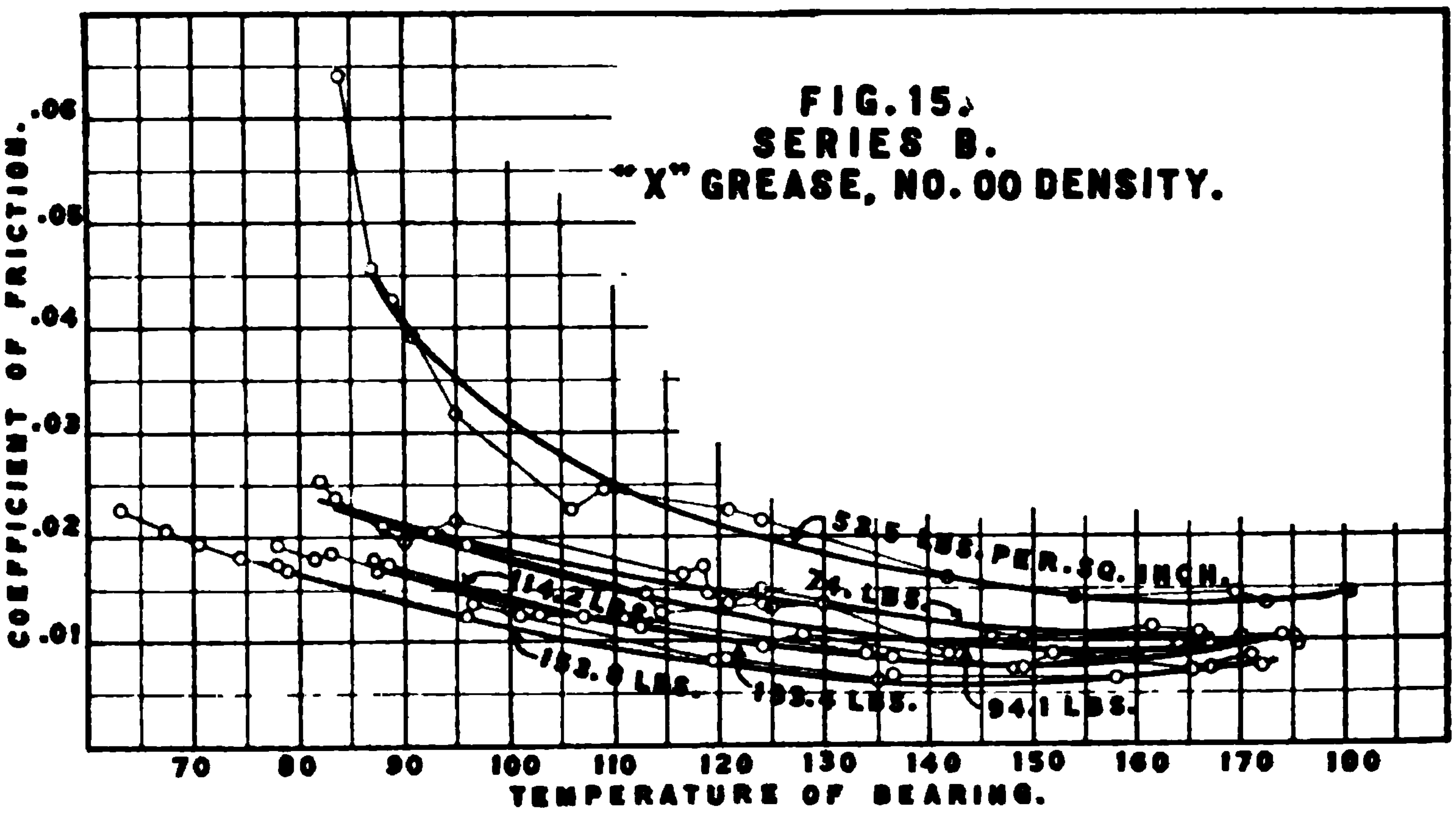


FIG. 15.
SERIES B.
"X" GREASE, NO. 00 DENSITY.
COEFFICIENT OF FRICTION.
TEMPERATURE OF BEARING.
52.5 LBS. PER. SQ. INCH.
74. LBS.
114.2 LBS.
152.8 LBS.
133.5 LBS.
94.1 LBS.

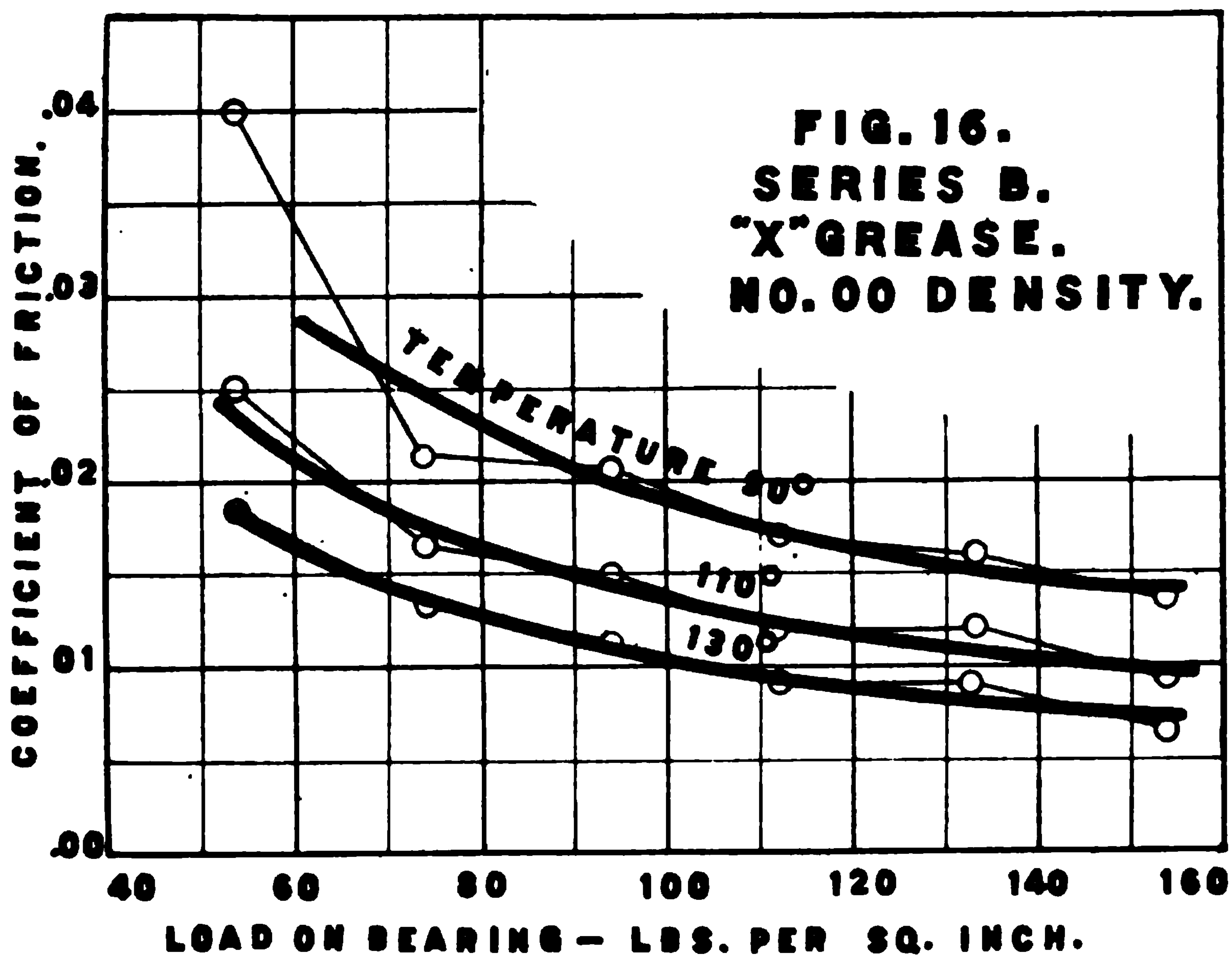


FIG. 16.
SERIES B.
"X" GREASE.
NO. 00 DENSITY.
COEFFICIENT OF FRICTION.
TEMPERATURE 90°
110°
130°
LOAD ON BEARING — LBS. PER SQ. INCH.

TABLE NO. 6.

X GREASE, NO. 00 DENSITY.

Series B. Loads of 53.5 to 153.8 lbs. per square inch. See figs. 15 and 16.
Diameter of journal, 1 1-4"; length, 2".
Grease cup used with spring actuated plunger.

Load on bearing, 53.5 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	84	.0640	Room temperature, 52 deg.
2	77	.0457	Forced grease in by hand.
3	89	.0425	
4	91	.0390	
5	89	.0425	
6	109	.0290- .0246	Second reading after forcing grease in by hand.
7	106	.0224	Warmed grease in cup to increase flow.
8	95	.0325	
9	95	.0313	
10	121	.0224	
11	124	.0213	
12	142	.0167	
13	142	.0157	
14	154	.0145	
15	155	.0134	
16	170	.0145	
17	172	.0134	
18	180	.0145	

Load on bearing, 74 lbs. per sq. inch. Surface speed of journal, 415 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	84	.0236	
2	84	.0236	
3	82	.0232	
4	91	.0195	
5	93	.0219	
6	95	.0212	
7	119	.0146	
8	116	.0163	
9	121	.0138	
10	118	.0171	
11	124	.0150	
12	147	.0097	
13	148	.0106	
14	148	.0101	
15	162	.0114	
16	166	.0109	
17	162	.0114	

Load on bearing, 94.1 lbs. per sq. in. Surface speed of journal, 390 feet per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	88	.0210	Room temperature, 71 deg.
2	92	.0204	
3	96	.0191	
4	115	.0128	
5	115	.0128	
6	113	.0146	
7	124–130	.0134	
8	130	.0131	
9	125	.0131	
10	146–149	.0102	
11	142	.0089	
12	146	.0102	
13	152–160	.0080	
14	165	.0096	
15	170–175	.0102	
16	175	.0096	

Load on bearing. 114.2 lbs. per sq. in. Surface speed of journal. 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	86–89	.0168	Temperature of room, 65 deg.
2	87	.0178	
3	89	.0173	
4	107	.0121	
5	110	.0126	
6	110	.0126	
7	134	.0089	
8	135	.0084	
9	136	.0084	
10	149	.0073	
11	148	.0079	
12	150	.0079	
13	172	.0100	
14	171–176	.0105	
15	170	.0100	

TABLE NO. 6—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks	Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 133.4 lbs. per sq. in. Surface speed of journal, 390 ft. per min.				Load on bearing, 153.8 lbs. per sq. in. Surface speed of journal, 370 ft. per min.			
1	78	.0192	Temperature of room, 64 deg.	1	63	.0226	Temperature of room, 64 deg.
2	81	.0180		2	68	.0203	
3	83	.0184		3	70	.0192	
4	111	.0121		4	75	.0180	
5	111	.0124		5	78	.0172	
6	112	.0112		6	79	.0168	
7	100	.0130		7	96	.0137	
8	102	.0126		8	96	.0117	
9	103	.0126		9	96	.0129	
10	125	.0101		10	120	.0082	
11	125–133	.0095		11	120	.0078	
12	128	.0106		12	119	.0080	
13	152	.0087		13	135	.0060	
14	152–157	.0090		14	137	.0062	
15	148	.0074		15	135	.0068	
16	165	.0070		16	167	.0072	
17	172	.0076		17	160	.0068	
18	171	.0087		18	158	.0064	

TABLE NO. 7.

X GREASE, NO. 3. DENSITY.

Series B. Loads of 53.5 to 153.8 lbs. per sq. inch. See figs. 17 and 18.
Diameter of journal, 1 1-4"; length, 2".
Grease cup with spring actuated plunger.

Load on bearing, 53.5 lbs. per sq. in. Surface speed of journal, 405 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	76	.0414	Room temperature, 72 deg.
2	80	.0342	
3	81	.0358	
4	82	.0352	
5	92–96	.0268	
6	94–97	.0246	
7	95	.0218	
8	110–114	.0190	
9	111	.0213	
10	111	.0213	
11	124	.0173	
12	125	.0185	
13	126	.0168	
14	141	.0145	
15	141	.0134	
16	140	.0151	
17	154	.0134	
18	156	.0112	
19	157	.0117	
20	170	.0101	
21	168	.0106	
22	170	.0140	

Load on bearing, 74 lbs. per sq. in. Surface speed of journal, 395 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	78	.0276	
2	79	.0252	
3	80	.0244	
4	95	.0187	
5	96	.0199	
6	97	.0211	
7	120	.0122	
8	119–122	.0134	
9	120	.0097	
10	135	.0081	
11	134	.0069	
12	135	.0065	
13	152	.0049	
14	155	.0049	
15	155	.0040	
16	168–171	.0041	
17	171	.0053	
18	171–189	.0057	

Load on bearing, 94.1 lbs. per sq. in. Surface speed of journal, 380 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	61	.0312	Room temperature, 67 deg.
2	69	.0262	
3	73	.0242	
4	75	.0204	
5	76	.0198	
6	96	.0131	
7	95	.0121	
8	95	.0124	
9	110	.0086	
10	111	.0115	
11	100–110	.0127	
12	124	.0079	
13	126	.0064	
14	125	.0067	
15	143	.0048	
16	141	.0054	
17	139	.0054	
18	161	.0045	
19	160	.0042	
20	160	.0048	

Load on bearing, 114.2 lbs. per sq. in. Surface speed of journal, 390 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0212	Room temperature, 67 deg.
2	77	.0173	
3	78	.0171	
4	79	.0171	
5	96	.0145	
6	96	.0137	
7	96	.0123	
8	108–111	.0123	
9	112	.0094	
10	110	.0094	
11	127	.0073	
12	125	.0068	
13	125	.0068	
14	140	.0059	
15	140	.0052	
16	140	.0052	
17	159	.0039	
18	161	.0037	
19	160	.0039	

TABLE NO. 7—Continued.

Load on bearing, 133.4 lbs. per sq. in. Surface speed of journal, 390 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	80	.0162	
2	83	.0119	
3	80	.0126	
4	97	.0090	
5	96	.0104	
6	96	.0099	
7	114	.0061	
8	113	.0052	
9	113	.0052	
10	131	.0049	
11	130	.0043	
12	132	.0038	
13	144	.0038	
14	146	.0034	
15	145	.0034	
16	158–162	.0038	
17	161	.0043	
18	161	.0043	

Load on bearing, 153.8 lbs. per sq. in. Surface speed of journal, 390 feet per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	56	.0285	Room temperature, 62 deg.
2	60	.0223	
3	64	.0156	
4	67	.0148	
5	71	.0145	
6	77	.0121	
7	93	.0098	
8	94	.0103	
9	95	.0090	
10	108	.0074	
11	108	.0070	
12	110	.0070	
13	123	.0060	
14	125	.0055	
15	124	.0059	
16	139	.0049	
17	140	.0047	
18	141	.0041	
19	158	.0035	
20	160	.0037	
21	160	.0037	

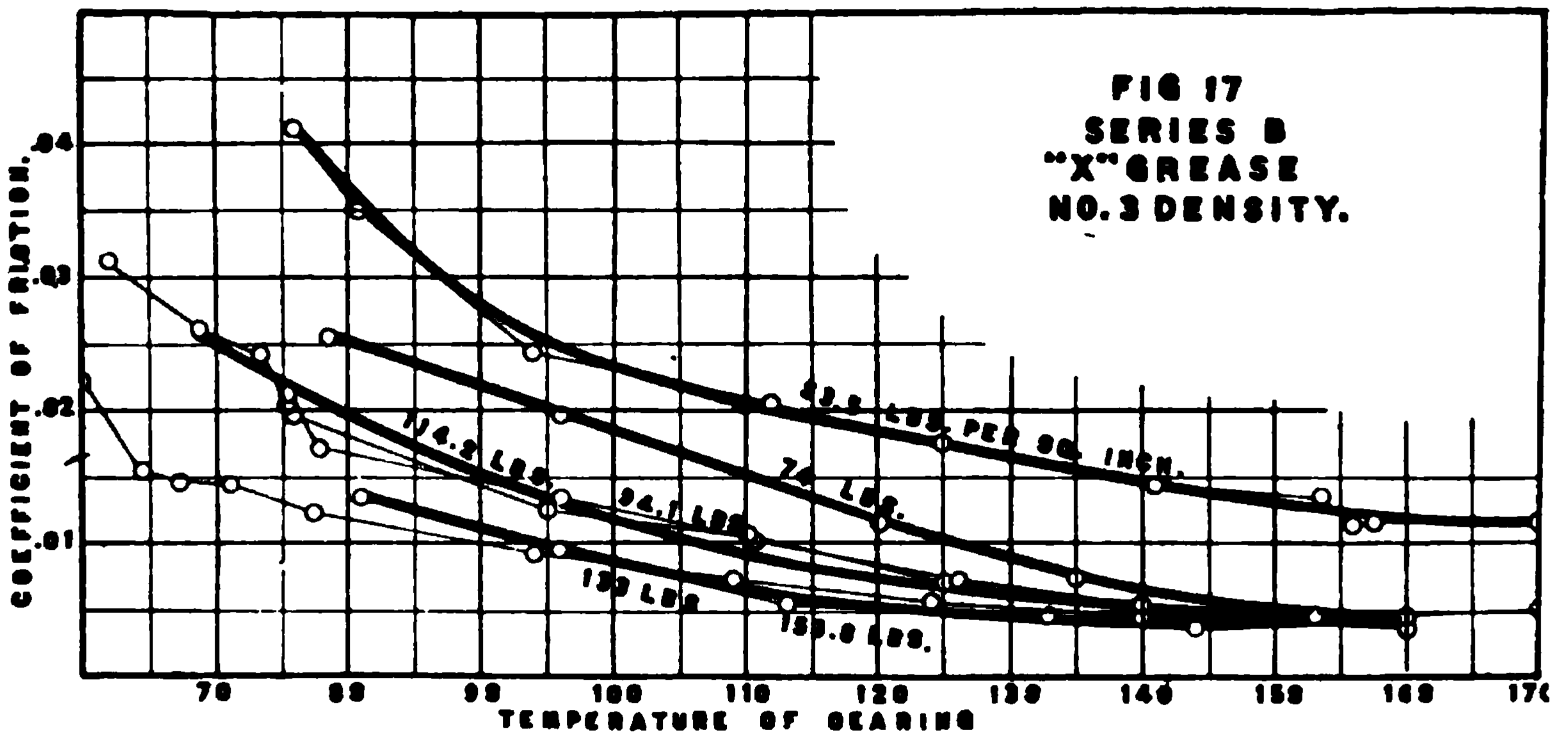


FIG 17
SERIES B
"X" GREASE
NO. 3 DENSITY.
COEFFICIENT OF FRICTION.
.04
.03
.02
.01
70
80
90
100
110
120
130
140
150
160
170
TEMPERATURE OF BEARING
43.8 LBS. PER SQ. INCH.
74 LBS.
114.2 LBS.
94.1 LBS.
133 LBS.
153.8 LBS.

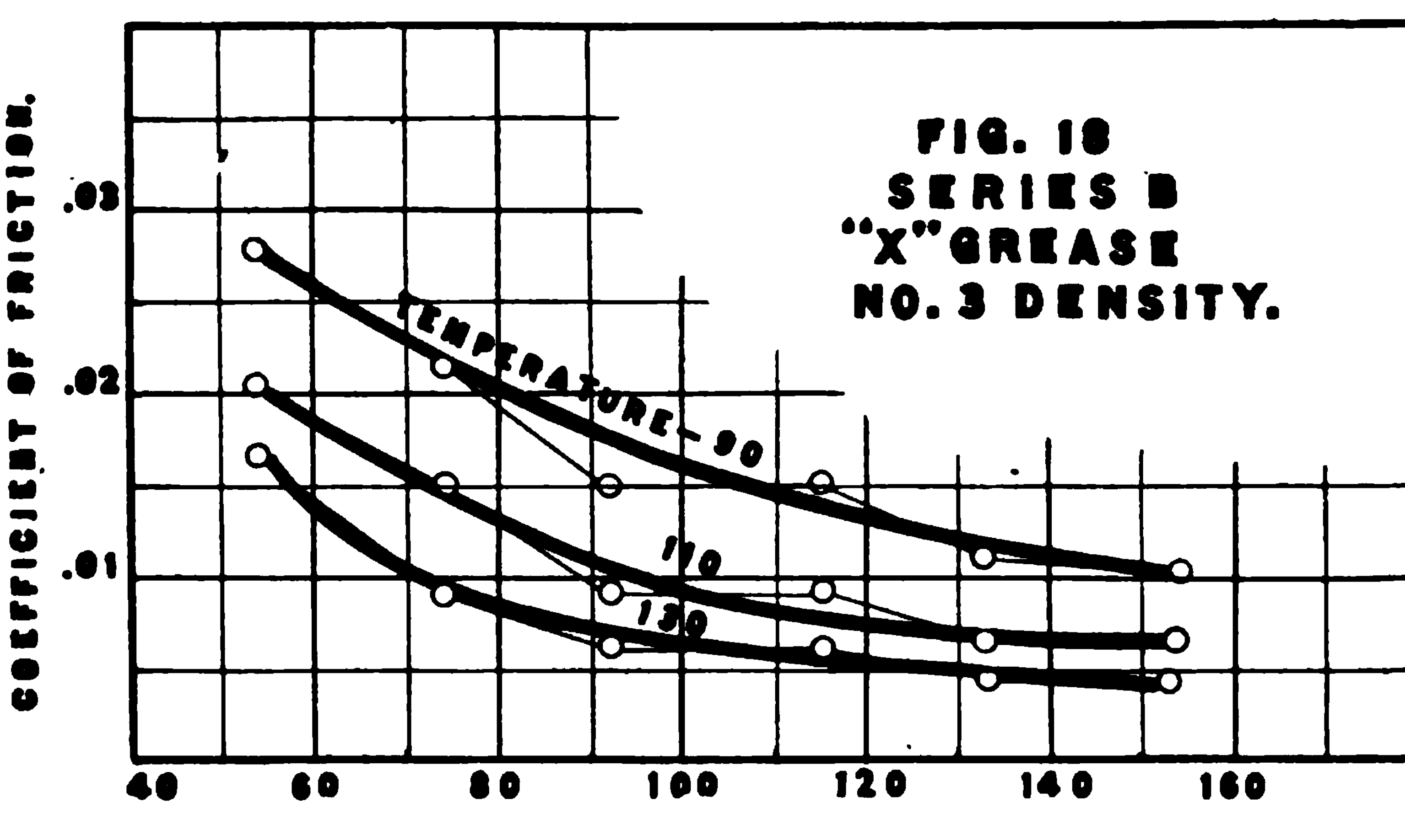


FIG. 18
SERIES B
"X" GREASE
NO. 3 DENSITY.
COEFFICIENT OF FRICTION.
.03
.02
.01
TEMPERATURE—90
110
130
40
60
80
100
120
140
160
LOAD ON BEARING — LBS. PER SQ. INCH.

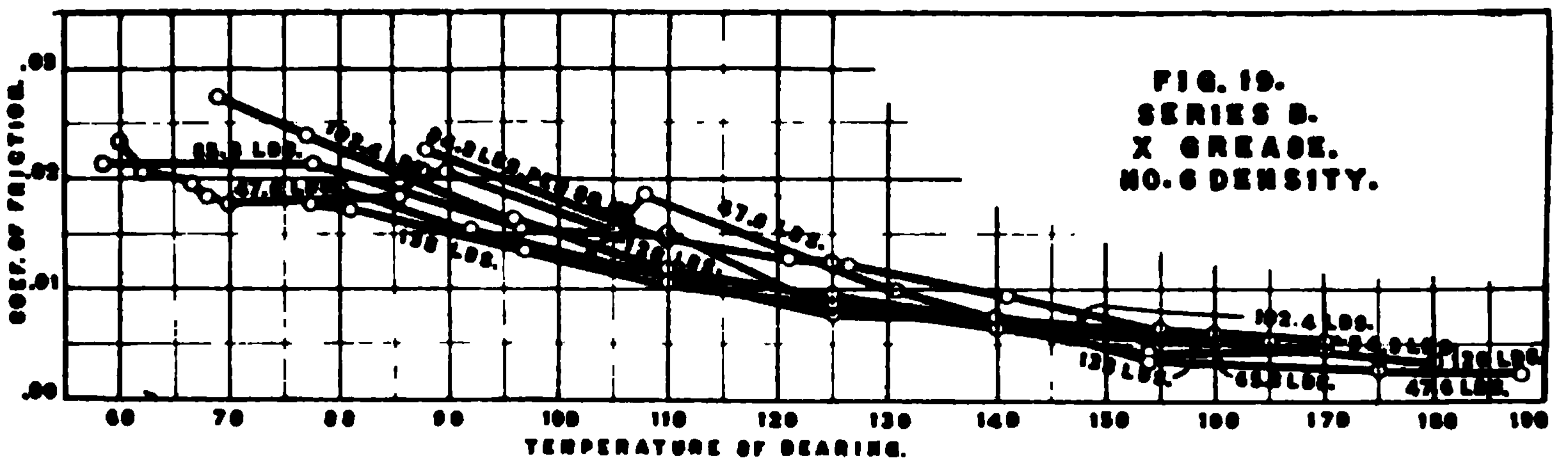


FIG. 19.
SERIES B.
X GREASE.
NO. 6 DENSITY.

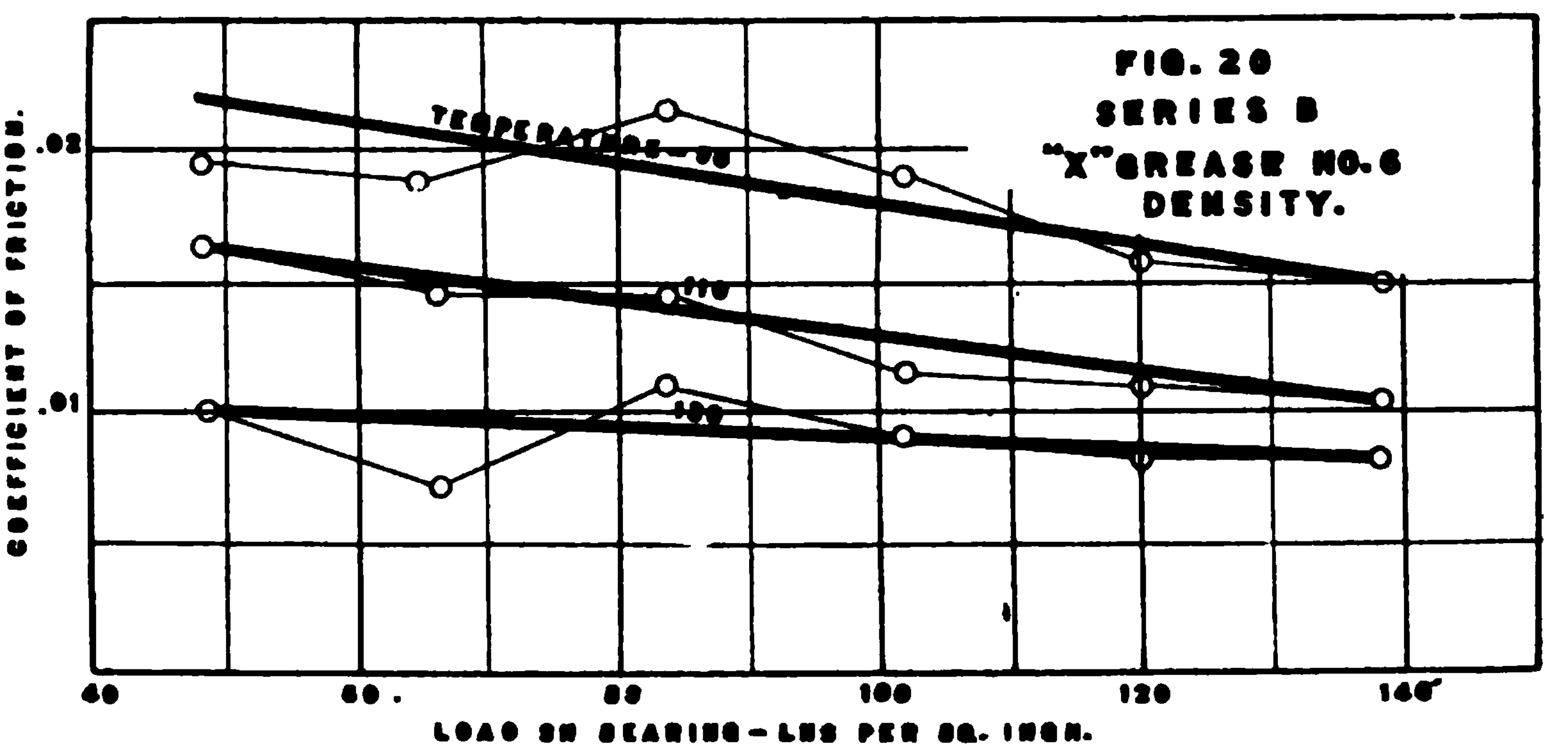


FIG. 20
SERIES B
"X" GREASE NO. 6
DENSITY.

TABLE NO. 8.

X GREASE, NO. 6 DENSITY.

Series B. Loads of 47.6 to 138 pounds per sq. inch. See figs. 19 and 20.
Diameter of journal, 1 1-4"; length, 2 1-4".
Grease was semi-liquid, fed by gravity to the bearing.

Load on bearing, 47.6 lbs. per sq. in. Surface speed of journal, 395 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	60	.0235	Room temperature, 62 deg.
2	62	.0207	Bearing was new when this test was started, and did not run very smoothly. A rapid feed of oil was necessary.
3	66	.0196	
4	68	.0185	
5	70	.0179	
6	85	.0185	
7	87	.0207	
8	89	.0207	
9	115–118	.0185	
10	115	.0157	
11	114	.0146	
12	115	.0100	
13	132	.0123	
14	131	.0089	
15	132	.0084	
16	155	.0039	
17	154	.0039	
18	155	.0034	
19	175	.0028	
20	177	.0033	
21	175	.0028	
22	187	.0022	
23	188	.0028	
24	190	.0022	

Load on bearing, 65.8 lbs. per sq. in. Surface speed of journal, 390 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0203	Room temperature, 53 degrees.
2	49	.0260	
3	58	.0212	
4	75–78	.0252	
5	80	.0236	
6	78	.0195	
7	95–100	.0163	
8	97	.0138	
9	94	.0163	
10	110	.0122	
11	110	.0106	
12	122–126	.0089	
13	125	.0081	
14	125	.0073	
15	138–144	.0057	
16	142	.0073	
17	140	.0065	
18	154	.0048	
19	154	.0049	
20	154	.0041	

TABLE NO. 8—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 84.3 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	88	.0255	After the preceding run, the journal was run about three hours to wear the bearing surfaces smooth. It now runs much better.
2	89	.0204	
3	86	.0223	
4	110	.0151	
5	111	.0145	
6	110	.0150	
7	127	.0121	
8	125	.0124	
9	121	.0127	
10	142–146	.0101	
11	140	.0095	
12	140	.0082	
13	155	.0063	
14	155	.0069	
15	155	.0063	
16	168–172	.0057	
17	173	.0050	
18	171	.0054	
Load on bearing, 102.4 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	70	.0276	
2	75	.0239	
3	77	.0228	
4	78	.0223	
5	96	.0161	
6	109	.0109	
7	110	.0130	
8	110	.0119	
9	122	.0091	
10	126	.0096	
11	125	.0093	
12	140	.0083	
13	160	.0060	
14	160	.0070	
15	162	.0052	

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 120 lbs. per sq. in. Surface speed of journal, 395 ft. per min.			
1	80	.0191	
2	81	.0186	
3	82	.0193	
4	90	.0160	
5	93	.0142	
6	93	.0155	
7	110	.0106	
8	109	.0120	
9	110	.0109	
10	125	.0071	
11	124	.0084	
12	127	.0084	
13	142	.0080	
14	141	.0071	
15	140	.0071	
16	159	.0062	
17	160	.0053	
18	163	.0049	
19	176	.0035	
20	176–179	.0038	
21	181	.0033	
Load on bearing, 138 lbs. per sq. in. Surface speed of journal, 390 ft. per min.			
1	77	.0177	
2	80	.0171	
3	83	.0173	
4	96	.0131	
5	98	.0130	
6	108–112	.0108	
7	109	.0100	
8	126	.0081	
9	138–143	.0069	
10	141	.0065	
11	158–165	.0054	

TABLE NO. 9.

Y GREASE, NO. 5 DENSITY.

Series B. Loads of 53.7 to 154.4 pounds per sq. inch. See figs. 21 and 22.
Diameter of journal, 1 1-4"; length, 2".

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 53.7 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	90	.0378	Compression grease cup used. Observations taken immediately after feeding grease to bearing.
2	90	.0280	
3	95	.0290	
4	100	.0266	
5	104	.0266	
6	108	.0234	
7	82	.0234	
8	84	.0234	
9	95	.0256	
10	100	.0234	
11	104	.0234	
12	108	.0244	
Second test at load of 53.7 lbs. per sq. inch. Surface speed of journal, 395 ft. per min.			
1	138	.0240	Compression grease cup used. Observations were made immediately after feeding grease.
2	151	.0240	
3	153	.0267	
4	140–158	.0246	
5	156	.0267	
6	157	.0252	
7	173	.0272	
8	190	.0278	
Load on bearing, 74.1 lbs. per sq. in. Surface speed of journal, 410 ft. per min.			
1	77	.0244	Compression grease cup used.
2	80	.0244	
3	82	.0210	
4	83	.0396	Observation after running ten minutes without feeding grease to bearing.
5	83	.0201	
6	82	.0210	
Second test at load of 74.1 lbs. per sq. in. Surface speed of journal, 410 ft. per min.			
1	110	.0146	Compression grease cup used.
2	116	.0162	Reading taken after running three minutes without feeding grease to bearing.
3	118	.0146	Read immediately after feeding grease.
4	120	.0162	Three minutes without feeding grease.
5	118	.0146	Read after feeding grease.
6	160	.0220	
7	164	.0236	Read two minutes after feeding grease.
8	160	.0220	Read after feeding grease.
9	183	.0260	Read after feeding grease.
10	190	.0260	
Load on bearing, 94.4 lbs. per sq. in. Surface speed of journal, 405 ft. per min.			
1	83	.0170	Compression grease cup used.
2	84	.0345	Read three minutes after feeding grease.
3	84	.0170	Read after feeding grease.
4	84	.0308	Four minutes after feeding grease.
5	84	.0166	Read after feeding grease.
6	86	.0153	Read after feeding grease.
7	92	.0173	Read after feeding grease.
8	94	.0198	Read after feeding grease.
9	96	.0186	Read after feeding grease.
10	118	.0152	Read after feeding grease.
11	128	.0192	Read after feeding grease.
12	143	.0243	Read after feeding grease
13	157	.0204	Read after feeding grease

TABLE NO. 9—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Second test at load of 94.4 lbs. per sq. in. Grease cup with spring loaded plunger used. Surface speed of journal, 400 ft. per min.			
1	73	.0228	
2	77	.0228	
3	80	.0224	
4	84	.0217	
5	88	.0200	
6	92	.0196	
Third test at load of 94.4 lbs. per sq. in. Surface speed of journal. 400 ft. per min.			
1	61	.040	Spring grease cup with constant feed.
2	70	.0345	
3	79	.0330	
4	84	.0256	Forced grease by hand
5	100	.0225	
6	109	.0192	
7–8	113	.0170	Forced grease by hand.
8	127	.0150	
9	145	.0142	
10	148–154	.0145	
11	143	.0154	
Load on bearing, 114.4 lbs per sq. in. Surface speed of journal, 380 to 425 ft. per min			
1	88	.0325	Spring grease cup used.
2	89	.0300	
3	94	.0280	Forced grease in by hand before reading.
4	86	.0168	
5	89	.0152	
6	98	.0155	
7	98	.0178	
8	102	.0126	Forced grease in by hand before reading.
9	104	.0147	
10	106	.0180	
11	136–145	.0149	
Second test at load of 114.4 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	79	.024	Spring grease cup used.
2	81	.024	
3	85	.0260	
4	88	.0190	
5	88	.0152	
6	88	.0188	
7	84	.0175	
Load on bearing, 133.4 lbs per sq. in. Surface speed of journal, 408 ft. per min.			
1	78	.0175	Spring grease cup used.
2	98	.0140	
3	108	.0133	
4	112	.0173	
5	136	.0144	
6	136	.0150	
7	129–132	.0130	
8	128–140	.0085	
9	152	.0079	
Second test at load of 133.4 lbs. per sq. in. Surface speed of journal, 408 ft. per min.			
1	69	.0199	
2	74	.0163	
3	80–85	.0158	
4	87	.0164	
5	88–98	.0159	
6	96	.0160	
Load on bearing, 154 lbs. per sq. in. Surface speed of journal, 425 ft. per min.			
1	80–85	.0181	Spring grease cup used.
2	85	.0144	
3	90	.0128	
4	92	.0133	

TABLE NO. 9—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks	Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Second test at load of 154 lbs. per sq. in. Surface speed of journal, 410 ft. per min.				Third test at load of 154 lbs. per sq. in. Surface speed of journal, 420 ft. per min.			
1	94	.0125	Spring grease cup used.	1	91	.0122	
2	106	.0113		2	89	.0137	
3	117	.0094		3	98–106	.0094	
4	162–168	.0095		4	118–127	.0094	
5	137	.0098		5	147	.0086	
6	124	.0066		6	152	.0094	
7	122	.0084					
8	143	.0112					
9	140	.0109					

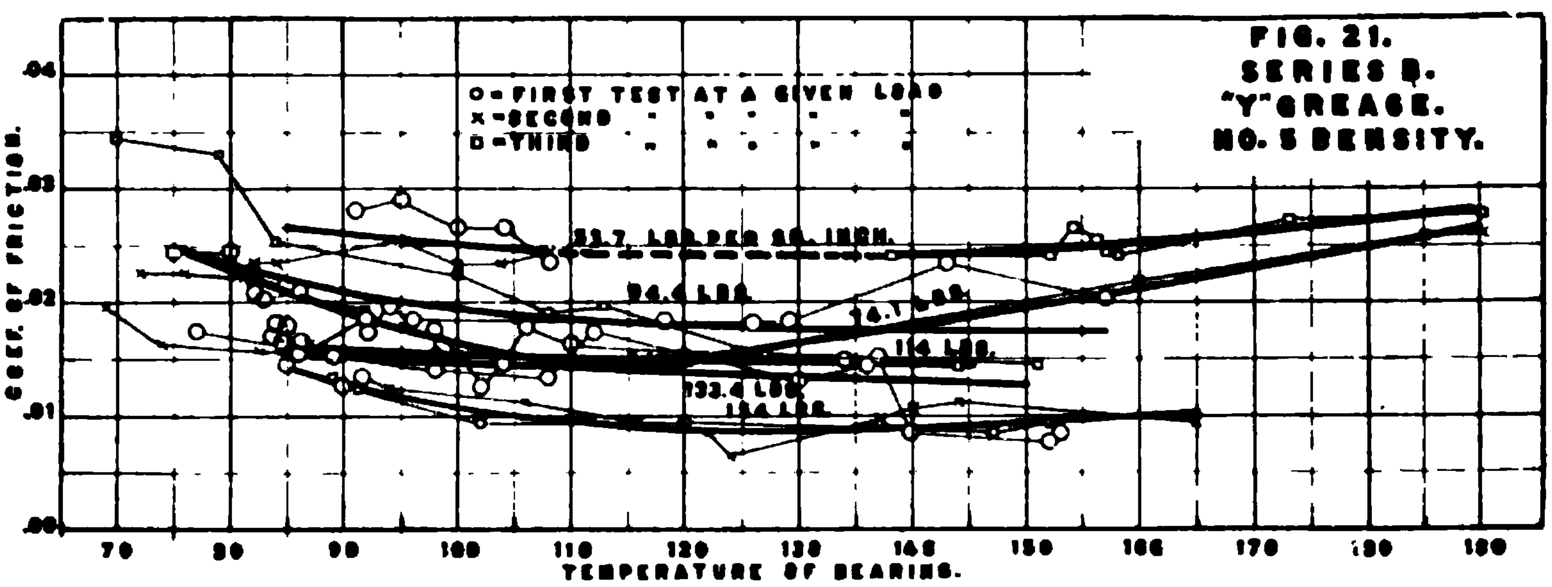


FIG. 21.
SERIES D.
"Y" GREASE.
NO. 5 DENSITY.

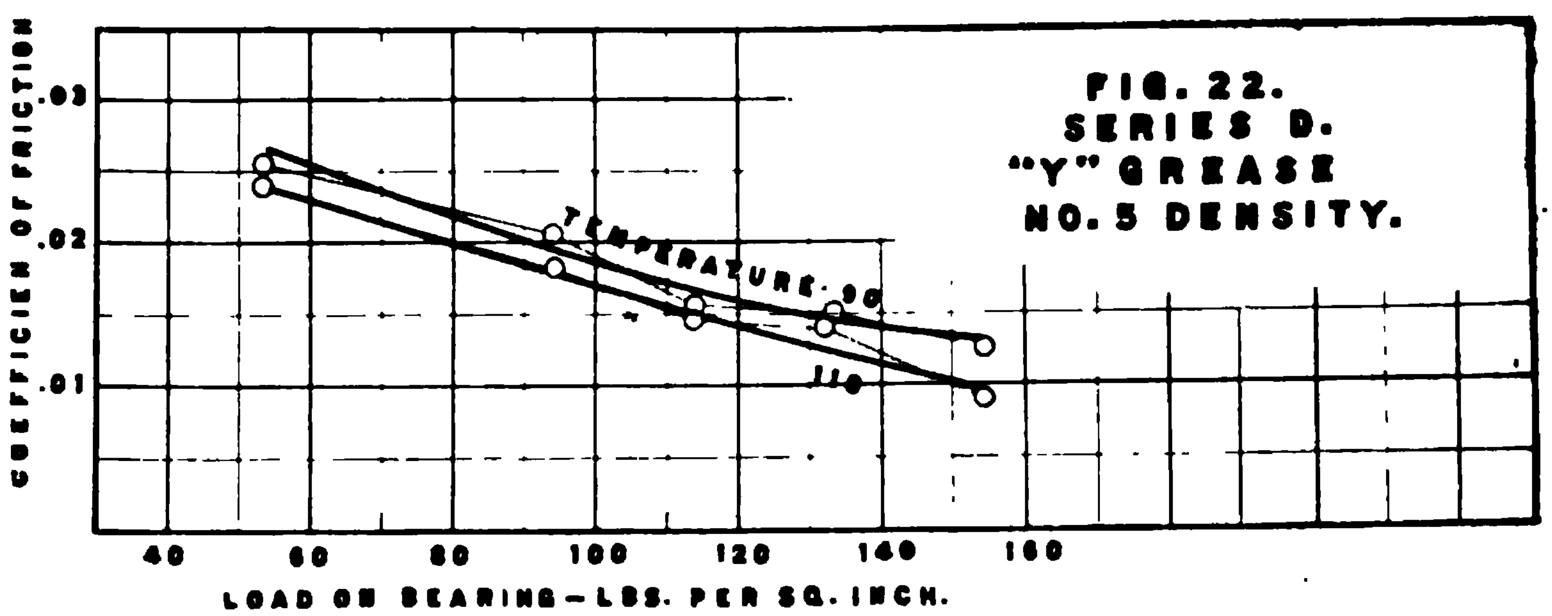


FIG. 22.
SERIES D.
"Y" GREASE
NO. 5 DENSITY.

TABLE NO. 10.

Y GREASE, NO. 3 DENSITY.

Series B. Loads of 53.7 to 154.4 pounds per sq. inch. See figs. 23 and 24.
Diameter of journal, 1 1-4"; length, 2".

Load on bearing, 53.7 lbs. per sq. in. Surface speed of journal, 350 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0236	Spring grease cup used.
2	79	.0258	
3	108–116	.0156	
4	120	.0145	
5	125–140	.0145	
6	149	.0134	
7	130–149	.0179	
8	100–108	.0178	
9	91	.0190	
10	85	.0200	
11	83	.0275	
12	82	.0200	

Load on bearing, 74.2 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	70	.0244	
2	72	.0220	
3	76	.0220	
4	100–119	.0145	
5	90–100	.0154	
6	86	.0179	
7	99	.0170	
8	130–140	.0138	
9	134	.0133	
10	130	.0122	
11	125	.0110	
12	107	.0093	
13	97	.0169	
14	96	.0212	

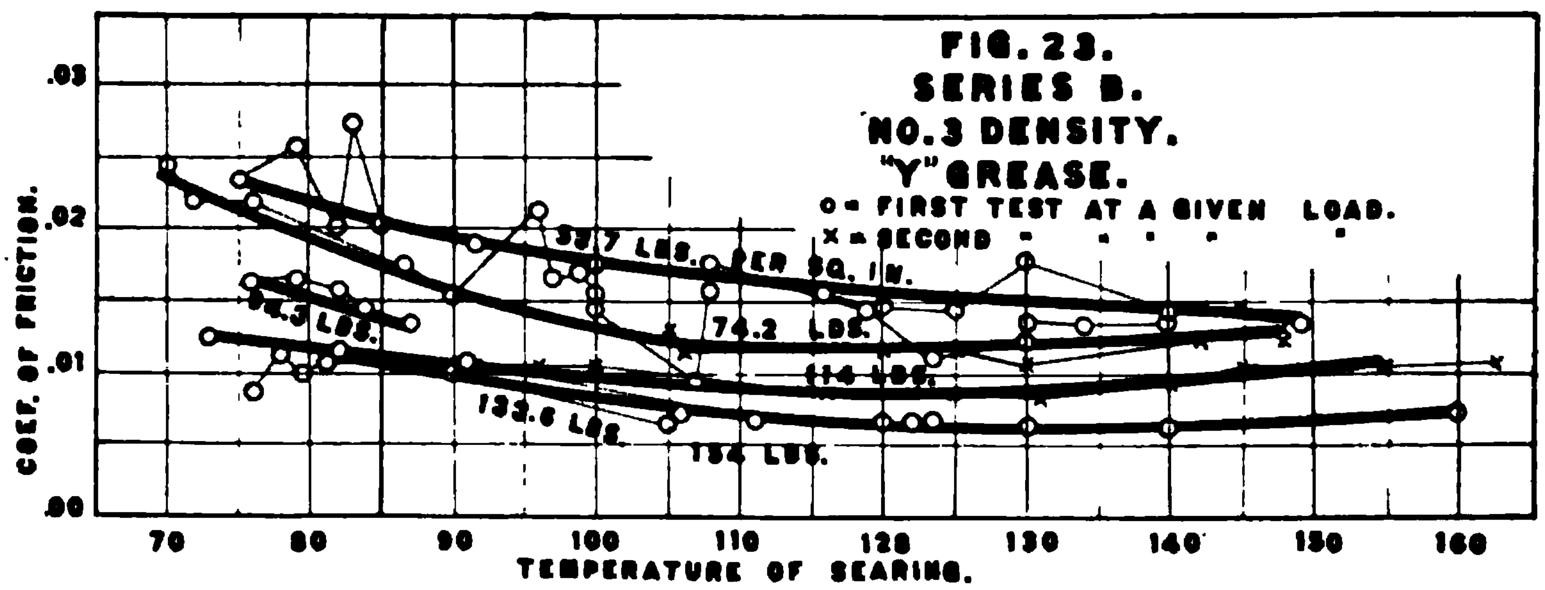


FIG. 23.
SERIES B.
NO. 3 DENSITY.
"Y" GREASE.

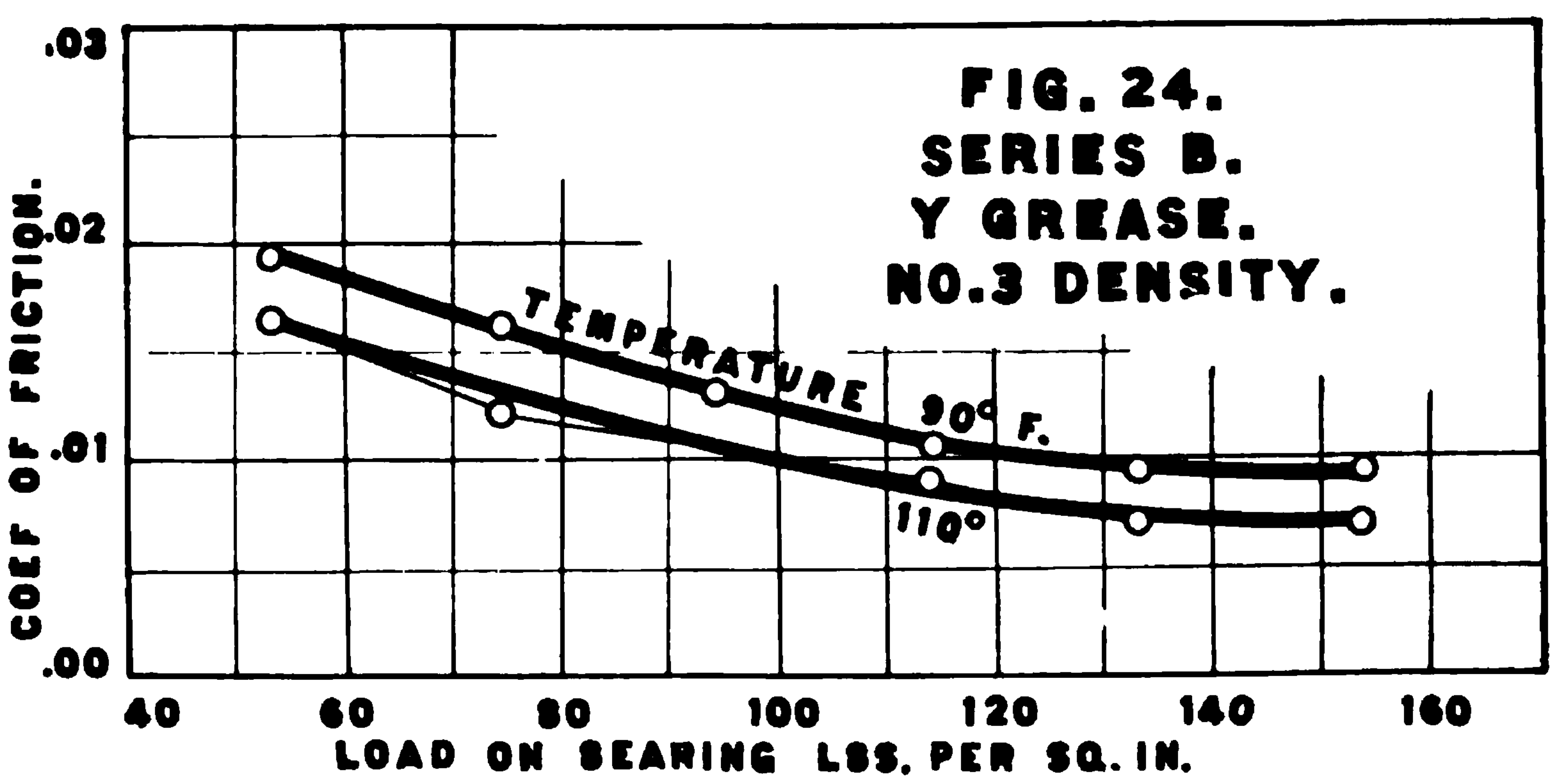


FIG. 24.
SERIES B.
Y GREASE.
NO. 3 DENSITY.

TABLE NO. 10—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Second test at load of 74.2 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	106	.0114	
2	105	.0130	
3	120–125	.0117	
4	130	.0106	
5	142–148	.0121	
6	148	.0130	
7	144	.0148	
Load on bearing, 94.3 lbs. per sq. in. Surface speed of journal. 425 ft. per min.			
1	76	.0162	
2	79	.0166	
3	82	.0159	
4	84	.0143	
5	87	.0134	
Load on bearing, 114.4 lbs. per sq. in. Surface speed of journal, 425 ft. per min.			
1	77	.0089	
2	78	.0115	
3	80	.0100	
4	82	.0113	
5	84	.0110	

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Second test at load of 114.4 lbs. per sq. in. Surface speed of journal, 425 ft. per min.			
1	61	.0198	
2	98	.0105	
3	90	.0102	
4	116	.0087	
5	123	.0087	
6	134	.0082	
7	142	.0092	
8	145	.0105	
9	153	.0105	
10	163	.0107	
Load on bearing, 133.6 lbs. per sq. in. Surface speed of journal, 375 ft. per min.			
1	81	.0148	
2	81	.0108	
3	91	.0108	
4	111	.0069	
5	123	.0068	
6	122	.0081	
7	122	.0067	
Load on bearing, 154.4 lbs. per sq. in. Surface speed of journal, 410 ft. per min.			
1	73	.0123	
2	90	.0100	
3	100–106	.0072	
4	105	.0064	
5	112–120	.0065	
6	130	.0061	
7	140–145	.0061	
8	158–161	.0072	

TABLE NO. 11.

Y GREASE. NO. 2 DENSITY.

Series B. Loads of 53.5 to 154 pounds per sq. inch. See figs. 25 and 26.
Diameter of bearing, 1 1-4"; length, 2".
Compression grease cup used.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 53.5 lbs. per sq. in. Surface speed of journal, 420 to 450 ft. per min.			
1	69	.0585	Room temperature, 70 degrees.
2	78	.0540	Reversed motor.
3	90	.0720	Grease fed after observation.
4	96	.0540	
5	96	.0338	Motor reversed.
6	96	.0372	
7	..	.0372	Motor reversed.
8	..	.0327	Motor reversed.
9	100	.0360	
10	100	.0360	Motor reversed.
11	100	.036	Motor reversed.
12	102	.0314	
13	102	.0314	Motor reversed.
14	104	.0566	Grease fed after observation.
15	...	.0250	
16	106	.027	
17	120	.0360	
18	121	.0405	Motor reversed.
19	121	.0400	Grease fed after observation.
20	118	.0282	
21	118	.0286	Motor reversed.
22	126	.0305	
Load on bearing, 73.5 lbs. per sq. in. Surface speed of journal, 375 to 420 ft. per min.			
1	62	.0433	Room temperature, 64 deg.
2	68	.0417	
3	70	.0417	Motor reversed.
4	76	.0400	
5	81	.0400	
6	84	.0360	Motor reversed.
7	86	.0320	
8	88	.0320	Motor reversed.
9	92	.0320	
10	96	.0390	Unsteady. Grease fed after observation.
11	..	.0307	
12	96	.0307	
13	98	.0257	
14	98	.0252	Motor reversed.
15	116	.0237	Ran fifty minutes without feeding grease.
16	...	.0250	
17	108	.0250	
Load on bearing, 93.5 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	75	.0303	Room temperature, 68 deg.
2	80	.0303	
3	88	.0253	Motor reversed.
4	89	.0253	
5	90	.0253	Motor reversed.
6	93	.0250	
7	..	.0250	Motor reversed.
8	99	.0233	
Load on bearing, 114 lbs. per sq. in. Surface speed of journal, 405 ft. per min.			
1	59	.0336	Room temperature, 61 deg.
2	64	.0336	Motor reversed.
3	70	.0331	
4	73	.0331	Motor reversed.
5	77	.0291	Grease fed at 5 minutes.
6	80	.0291	Motor reversed.
7	82	.0218	
8	..	.0218	Motor reversed.
9	85	.0185	
10	87	.0185	Motor reversed.
11	92	.0185	Motor reversed at every observation for the remainder of this run.

TABLE NO. 11—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
12	93	.0178	
13	96	.0178	
14	98	.0165	Ran 125 minutes without feeding any additional grease.
15	109	.0189	
16	107	.0160	
17	106	.0160	
18	104	.0160	

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 133.5 lbs. per sq. in. Surface speed of journal, 380 ft. per min.			
1	67	.0238	Room temperature, 66 deg.
2	72	.0238	Motor was reversed after each observation.
3	77	.0189	
4	82	.0180	
5	92	.0166	
6	95	.0152	
Load on bearing, 154 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	72	.0186	Motor reversed after each observation.
2	78	.0186	
3	90	.0151	
4	104	.0162	
5	...	.0108	
6	...	.0093	
7	106	.0085	
8	110	.0104	

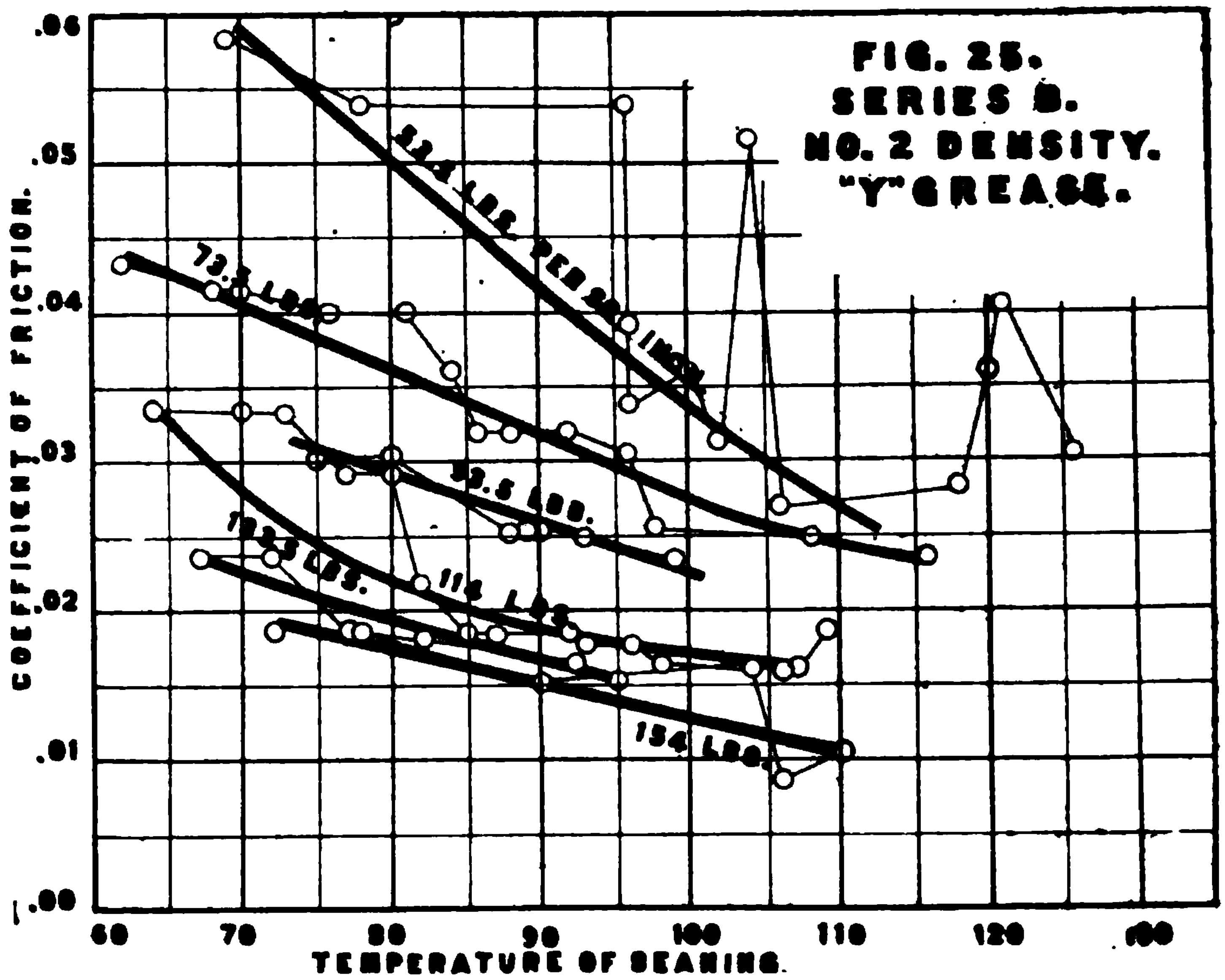


FIG. 25.
SERIES B.
NO. 2 DENSITY.
"Y" GREASE.
COEFFICIENT OF FRICTION.
TEMPERATURE OF BEARING.
.06
.05
.04
.03
.02
.01
.00
60
70
80
90
100
110
120
130

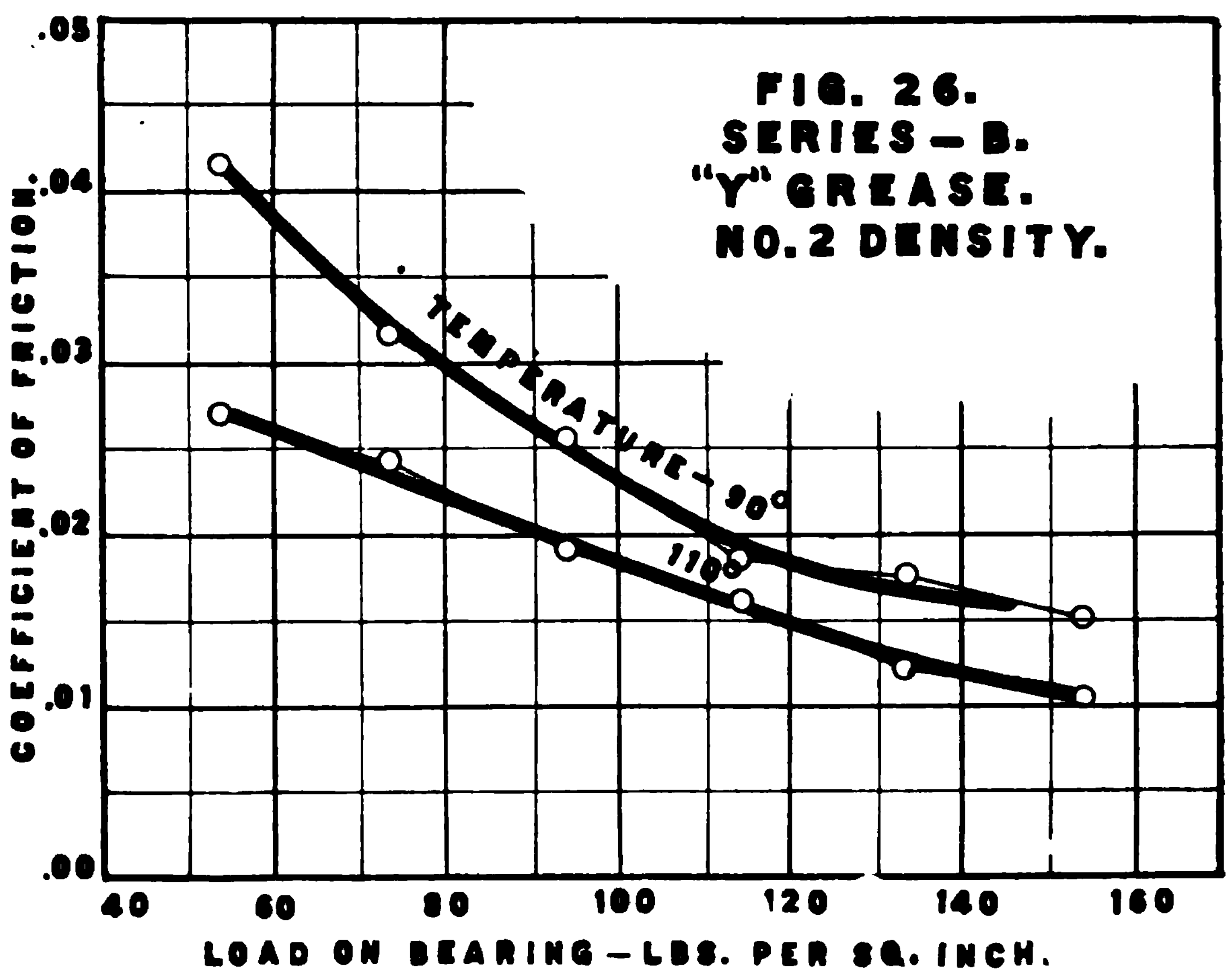


FIG. 26.
SERIES—B.
"Y" GREASE.
NO. 2 DENSITY.
TEMPERATURE—90°
110°
COEFFICIENT OF FRICTION.
LOAD ON BEARING—LBS. PER SQ. INCH.
.05
.04
.03
.02
.01
.00
40
60
80
100
120
140
160

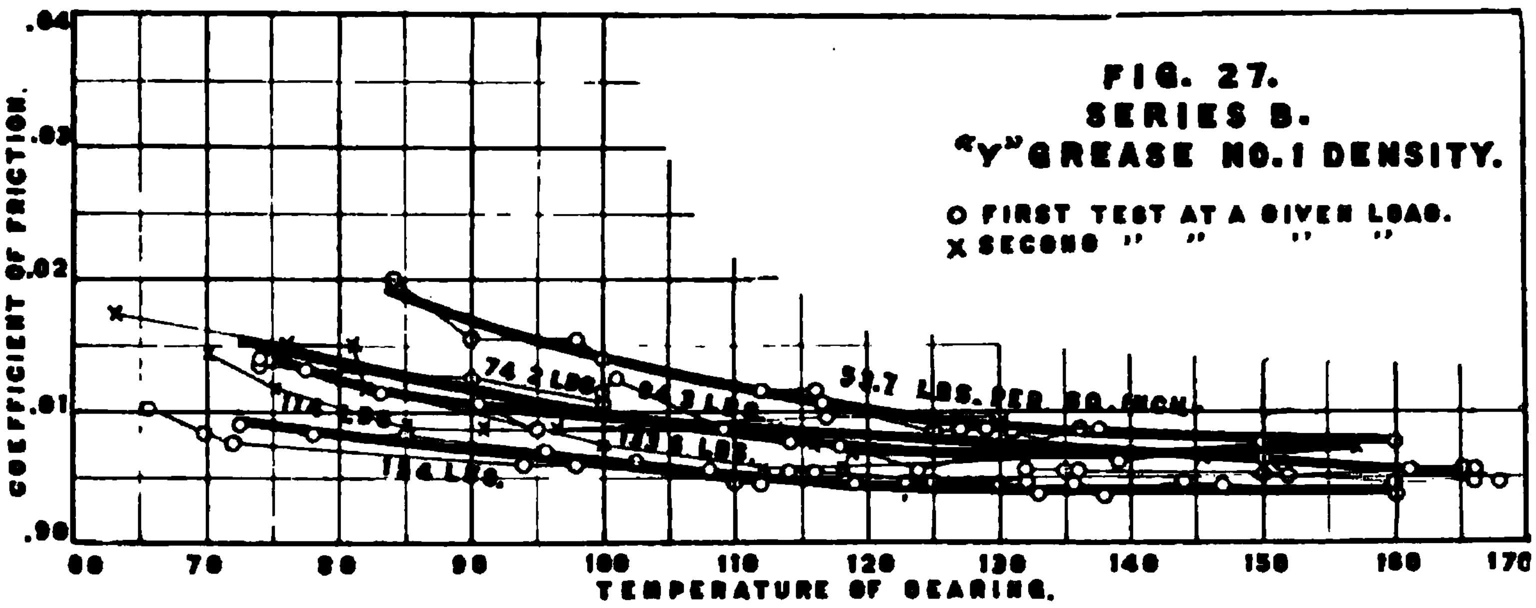


FIG. 27.
SERIES B.
"Y" GREASE NO. 1 DENSITY.
O FIRST TEST AT A GIVEN LOAD.
X SECOND " " " "
74.2 LBS.
94.3 LBS.
52.7 LBS. PER SQ. INCH
114 LBS.
133.5 LBS.
154 LBS.
COEFFICIENT OF FRICTION.
.04
.03
.02
.01
.00
60
70
80
90
100
110
120
130
140
150
160
170
TEMPERATURE OF BEARING.

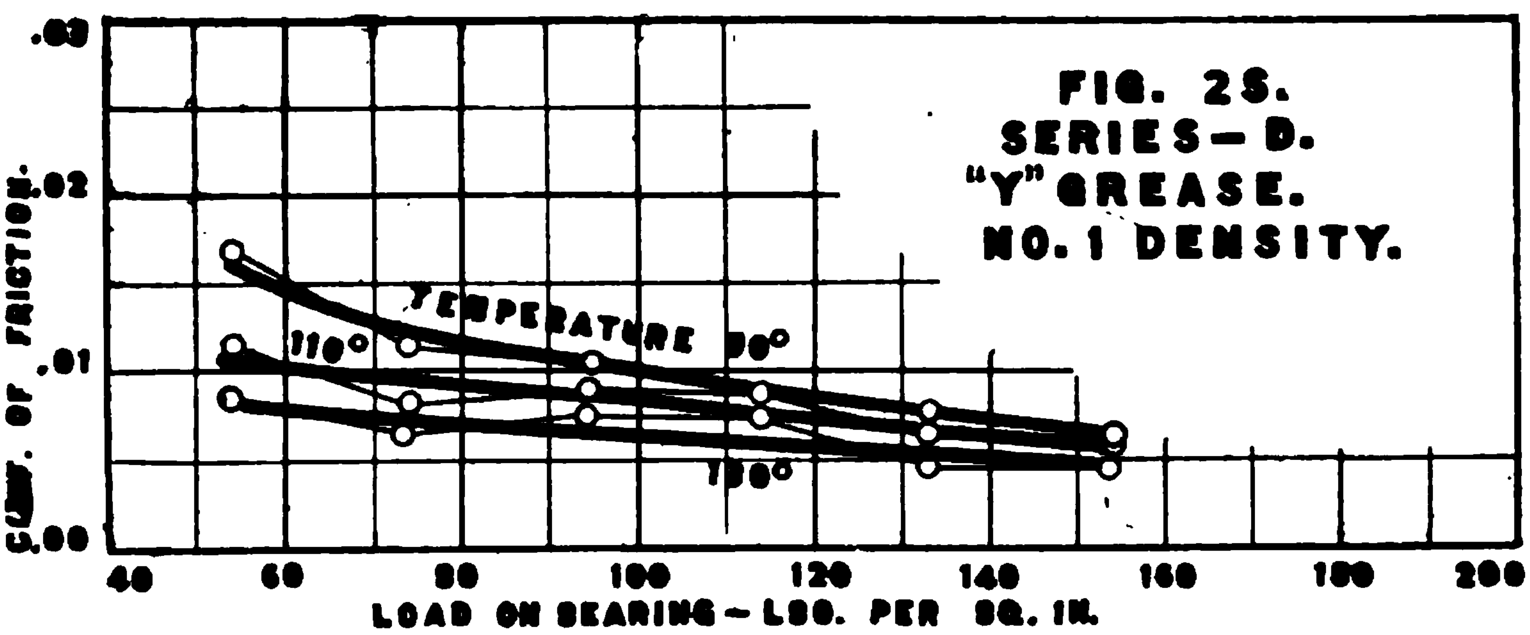


FIG. 28.
SERIES—D.
"Y" GREASE.
NO. 1 DENSITY.
TEMPERATURE 90°
110°
130°
COEF. OF FRICTION.
.03
.02
.01
.00
40
60
80
100
120
140
160
180
200
LOAD ON BEARING—LBS. PER SQ. IN.

TABLE. NO. 12.

Y GREASE, NO. 1 DENSITY.

Series B. Loads of 53.7 to 154 pounds per sq. inch. See figs. 27 and 28.
Diameter of bearing, 1 1-4″; length, 2 ′.

Load on bearing, 53.7 lbs. per sq. in. Surface speed of journal, 410 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	79	.0490	Spring feed grease cup used.
2	86	.0390	
3	84	.0200	
4	90–98	.0156	
5	100	.0140	
6	114	.0117	
7	117	.0107	
8	138	.0089	
9	129–136	.0089	
10	125	.0084	
11	160	.0078	

Load on bearing, 74.2 lbs. per sq. in. Surface speed of journal, 395 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	74	.0263	
2	77	.0132	Increased feed of grease before reading.
3	90–101	.0126	
4	100	.0114	
5	100	.0106	
6	124	.0057	
7	139	.0089	
8	136	.0089	
9	118	.0073	
10	109	.0088	

Second test at 74.2 lbs. per sq. in. Surface speed of journal, 345 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	63	.0179	
2	76–81	.0150	
3	82	.0118	
4	100–116	.0074	
5	112–118	.0059	
6	152–157	.0073	

Load on bearing, 94.3 lbs. per sq. in. Surface speed of journal, 410 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0140	
2	83	.0114	
3	90	.0108	
4	95	.0086	
5	127	.0095	
6	127	.0086	
7	131	.0086	
8	139	.0061	
9	152–165	.0050	
10	163	.0057	
11	117–130	.0096	
12	131	.0086	
13	141	.0080	
14	150	.0076	At temperature of 150 degrees lubrication is uncertain. The oil film could be maintained only by rapid feeding of grease.
15	161	.0089	
16	150	.0064	

Load on bearing, 114.4 lbs per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	77	.0184	
2	80	.0184	
3	94	.0173	
4	102	.0168	
5	115–120	.0108	
6	119	.0084	
7	115	.0071	
8	125–133	.0087	
9	138	.0084	Increased feed of grease.
10	130	.0068	
11	154–163	.0060	
12	162	.0065	
13	150–157	.0060	
14	142	.0068	

TABLE NO. 12—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Second test at load of 114.4 lbs. per sq. in. Surface speed of journal, 380 ft. per min.			
1	62	.0172	
2	70	.0142	
3	75	.0088	Increased feed of grease.
4	85–91	.0089	
5	96	.0089	
6	109–133	.0084	
7	119	.0068	
8	145	.0063	
9	140	.0084	
10	130–135	.0096	
Load on bearing, 133.4 lbs. per sq. in. Surface speed of journal, 380 ft. per min.			
1	72	.0090	
2	74	.0140	
3	78–85	.0083	
4	108	.0058	
5	119–123	.0045	
6	125–130	.0045	
7	135	.0047	
8	145	.0044	
9	143	.0047	
10	134–138	.0038	
11	160	.0038	
Load on bearing, 153.8 lbs. per sq. in. Surface speed of journal, 390 ft. per min.			
1	66	.0101	
2	70	.0086	
3	72	.0078	
4	93	.0060	
5	97	.0064	
6	111	.0047	
7	115	.0055	
8	125–132	.0047	
9	135	.0057	
10	152	.0051	
11	160–168	.0045	
12	136	.0055	

TABLE NO. 13.

GREASE, NO. 1.

Series C. Comparison of oil hole lubrication with compression grease cup, hand operated. Load on bearing, 114 pounds per sq. inch.

To test for oil hole lubrication, a measured quantity of grease was placed in the holes. Successive runs were then made without further addition of grease until the lubrication failed.

Oil hole lubrication. See fig. 29, curves 1a, 2a, 3a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1a.			
0	79	3	.092
10	145	69	.092
20	133	57	.033
30	145	69	.040
40	145	69	.040
50	142	66	.035
60	142	66	.035
70	150	74	.025
80	155	79	.025
90	142	66	.013
Second run, curves 2a.			
0	75	11	.107
10	..	..	.107
20	189	125	.092
30	187	123	.092
40	177	116	.074
50	176	115	.027
60	145	84	.027
85	137	66	.027
115	120	58	.027
140	134	74	.027
150	135	75	.027
175	136	76	.027
190	133	73	.018
Third run, curves 3a.			
0	70	1	.062
5	85	16	.062
10	117	48	.062
20	...	..	.062
30	123	53	.032
40	139	69	.032
50	...	..	.032
60	140	68	.032
90	133	61	.032
110	135	63	.025
120	136	62	.025
140	181	107	.035
180	158	82	.025
220	160	84	.032
240	168	92	.087

Lubrication failed at this point.

Grease cup lubrication. See fig. 29, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b.			
0	77	0	.030
3	88	11	.030
10	97	20	.025
20	113	36	.021
85	131	54	.017
120	145	68	.017
180	142	65	.022
180	142	65	.015
(The last reading was observed after forcing in grease.)			
Second run, curves 2b.			
0	85	2	.035
3	93	9	.035
6	100	17	.024
22	124	41	.022
22	124	41	.015
(The last reading was observed after forcing in grease.)			
30	122	39	.020
40	127	44	.020
65	141	58	.016
90	150	67	.013
100	142	59	.016
115	150	67	.014
116	...	...	.017

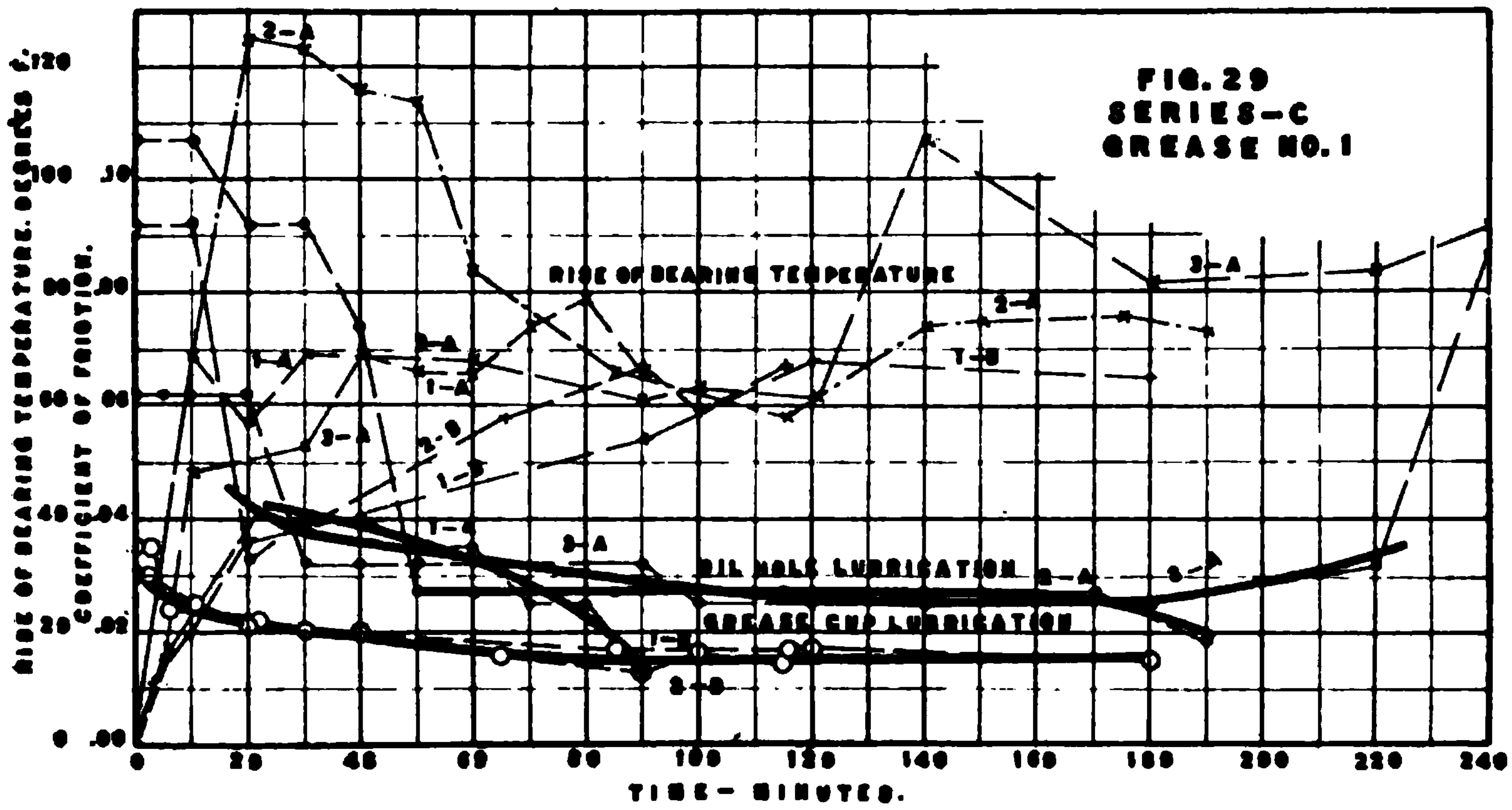


FIG. 29
SERIES—C
GREASE NO. 1
RISE OF BEARING TEMPERATURE
OIL HOLE LUBRICATION
GREASE CUP LUBRICATION
RISE OF BEARING TEMPERATURE. DEGREES C.
COEFFICIENT OF FRICTION.
TIME— MINUTES.

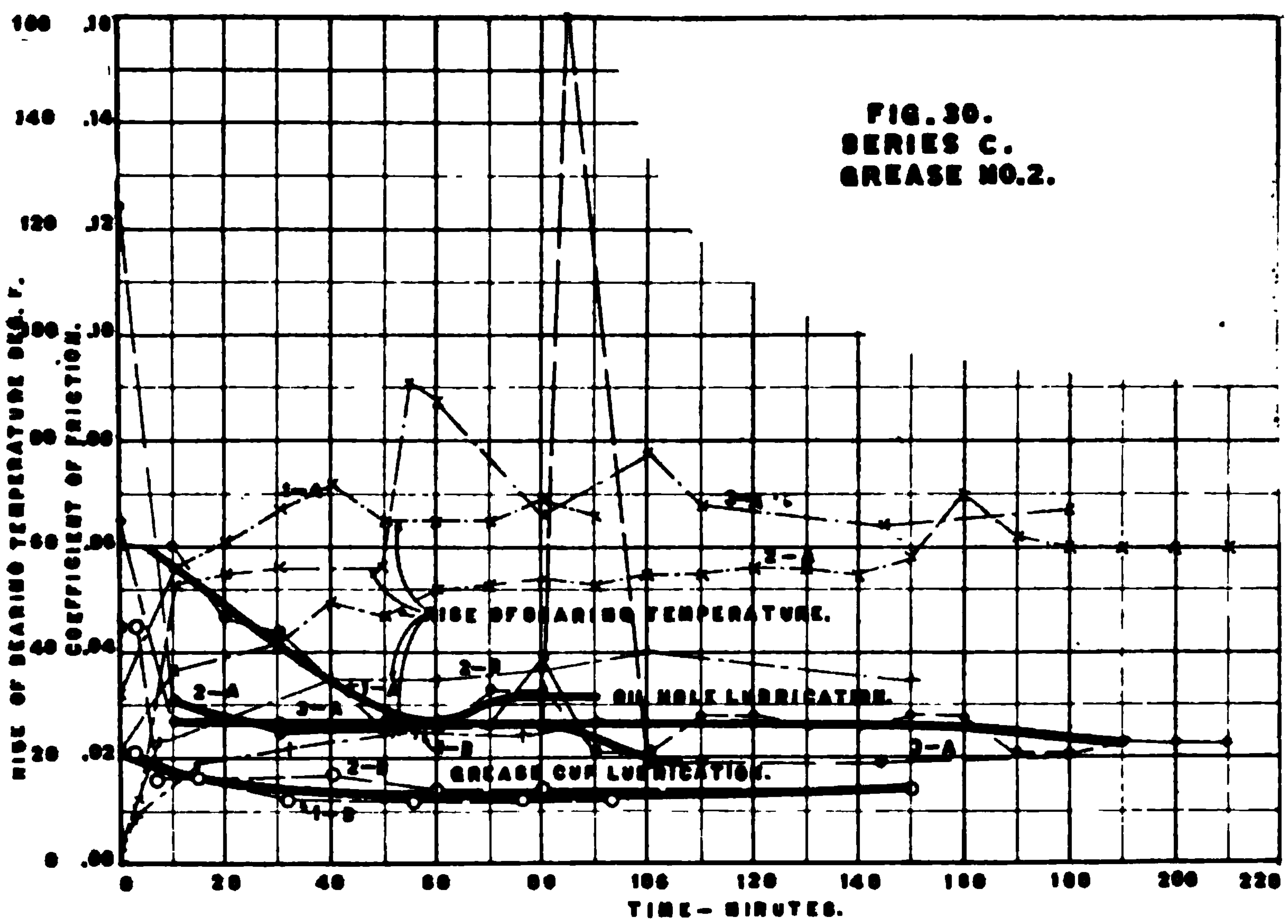


FIG. 30.
SERIES C.
GREASE NO. 2.
RISE OF BEARING TEMPERATURE.
OIL HOLE LUBRICATION.
GREASE CUP LUBRICATION.
RISE OF BEARING TEMPERATURE DEG. F.
COEFFICIENT OF FRICTION.
TIME— MINUTES.

TABLE NO. 14.

TEST SERIES C. GREASE NO. 2.

Comparison of oil hole lubrication with compression grease cup, hand operated.

Load on the bearing, 114 pounds per sq. inch.

Oil hole lubrication. See fig. 30, curves 1a, 2a, 3a.

Time, Minutes	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1a.			
0	102	32	.060
10	126	56	.060
20	131	61	.047
30	137	67	.044
40	142	72	.034
50	135	65	.026
60	135	65	.027
70	135	65	.026
80	139	69	.039
90	136	66	.021
Second run, curves 2a.			
0	105	22	.124
10	120	37	.031
30	125	42	.025
40	133	50	.025
50	130	47	.026
60	135	52	.026
70	136	53	.033
80	137	54	.033
90	136	53	.021
100	138	55	.021
110	138	55	.028
120	139	56	.028
130	139	56	.025
140	138	55	.026
150	141	58	.028
160	153	70	.028
170	145	62	.021
180	143	60	.021
190	143	60	.023
200	143	60	.023
210	143	60	.023
Third run, curves 3a.			
0	65	0	.065
3	84	12	....
10	125	53	.027
20	127	55	.027
30	128	56	.027
50	128	56	.027
60	160	88	.026
80	139	66	.026
85	...	..	.101
100	151	78	.019
110	141	68	.019
145	137	64	.019
180	140	67	.020

Grease cup lubrication. See fig. 30, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b			
0	90	1	.021
3	98	9	.021
15	108	19	.016
31	110	21	.012
56	115	25	.012
76	116	26	.012
93	119	29	.012
Second run, curves 2b.			
0	75	3	.045
3	83	12	.045
17	94	23	.016
40	107	35	.017
60	108	35	.014
80	110	37	.014
100	113	40	.014
150	111	35	.014

TABLE NO. 15.

TEST SERIES C. GREASE NO. 3.

Comparison of oil hole lubrication with compression grease cup, hand operated.

Load on the bearing, 114 pounds per sq. inch.

Oil hole lubrication. See fig. 31, curves 1a, 2a, 3a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1a. Ran 2¼ minutes before first observation.			
0	137	62	.046
7.5	160	85	.046
10	167	92	.082
15	169	94	.082
20	169	94	.029
25	162	87	.029
30	163	88	.015
35	158	83	.015
40	159	84	.0126
Second run, curves 2a.			
0	108	36	.063
5	136	64	.063
10	138	66	.063
15	138	66	.063
20	138	66	.036
30	140	68	.036
40	148	76	.035
50	148	76	.035
60	153	81	.027
70	149	77	.027
80	170	97	.065
90	160	87	.035
Third run, curves 3a.			
0	88	16	.080
2.5	100	28	.080
5	112	40	.080
7.5	122	50	.080
15	127	55	.080
20	141	69	.077
30	150	78	.067
40	150	78	....
50	176	104	.043
60	180	108	.043
70	170	98	.027
80	181	108	.027
90	171	98	.072
100	175	102	.040
106	172	99	.040

Grease cup lubrication. See fig. 31, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b.			
0	82	2	.033
5	95	15	.032
10	106	29	.033
20	116	36	.024
50	135	55	.017
65	145	65	.016
85	140	60	.020
100	140	60	.020
Second run, curves 2b.			
0	81	3	.039
10	110	32	.024
20	113	35	.022
60	146	68	.020

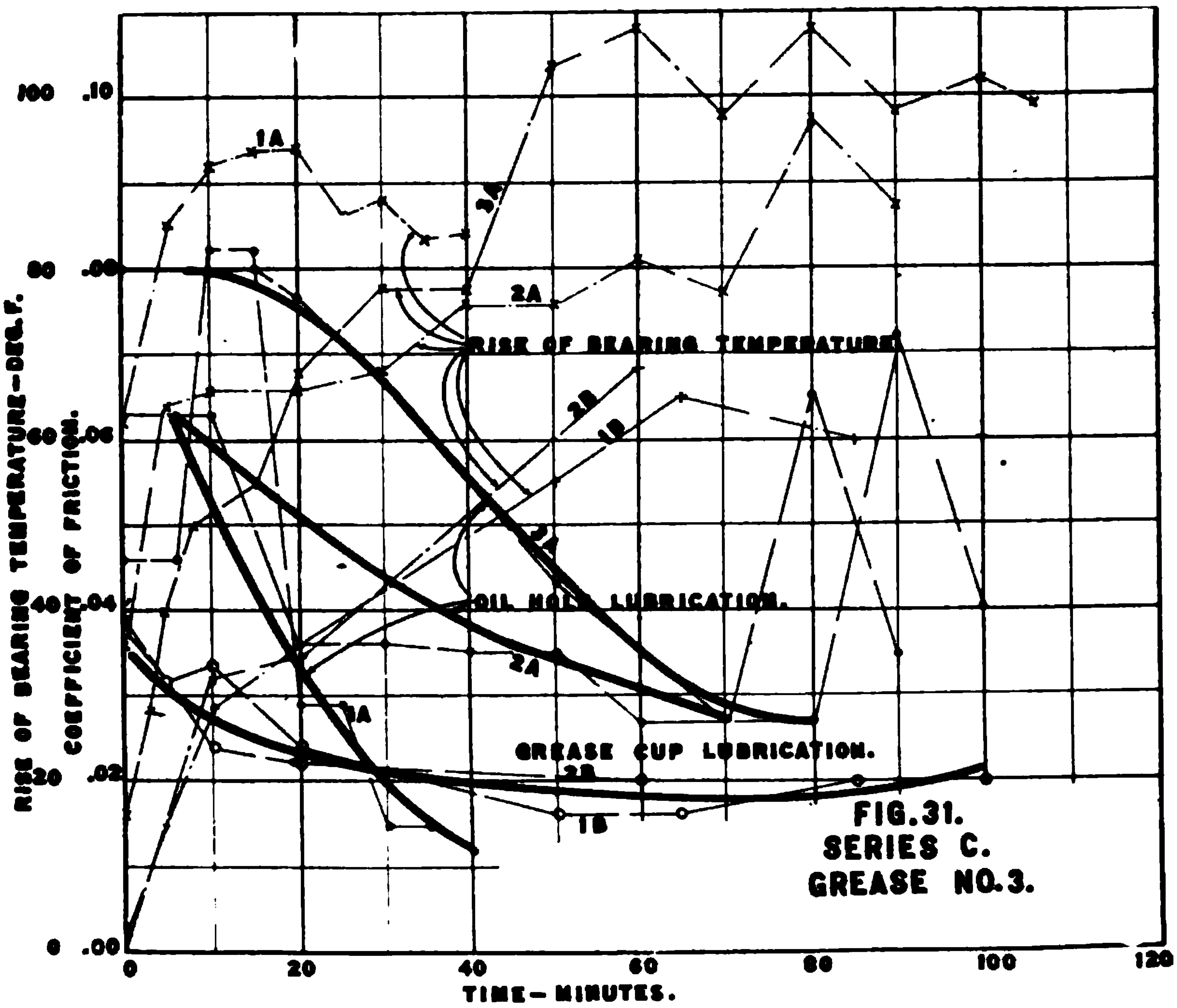


FIG. 31.
SERIES C.
GREASE NO. 3.

TABLE NO. 16.

TEST SERIES C, GREASE NO. 4.

Comparison of oil hole lubrication with compression grease cup, hand operated.

Load on the bearing, 114 pounds per sq. inch.

Oil hole lubrication. See fig. 32, curves 1a, 2a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1a.			
0	147	172	.122
3	164	104	.010
5	180	120	.116
10	169	108	.072
15	166	105	.073
20	168	108	.036
30	154	94	.028
40	145	85	.028
60	143	82	.026
70	154	93	.026
Second run, curves 2a.			
0	76	0	.041
3	92	16	.041
10	132	56	.066
20	137	61	.037
30	138	63	.038
40	142	68	.030
50	142	68	.030
60	162	88	.026
70	149	75	.026
80	144	70	.026
90	143	69	.026
100	140	66	.024
110	138	64	.024
120	138	64	.072
130	143	69	.102
140	196	122	.102

Grease cup lubrication, see fig. 32, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b.			
0	74	0	.078
2	90	16	.078
3	98	24	.078
12	114	40	.074
17	130	56	.063
26	145	71	.059
41	158	86	.050
56	165	89	.059
71	173	96	.047
86	178	101	.054
105	175	98	.044
Second run, curves 2b.			
0	86	5	.155
5	118	37	.055
10	133	51	.050
20	148	67	.047
30	170	89	.041
45	163	81	.040
60	173	91	.044
62	173	91	.053
65	...	..	.049
80	186	104	.044
110	180	98	.046

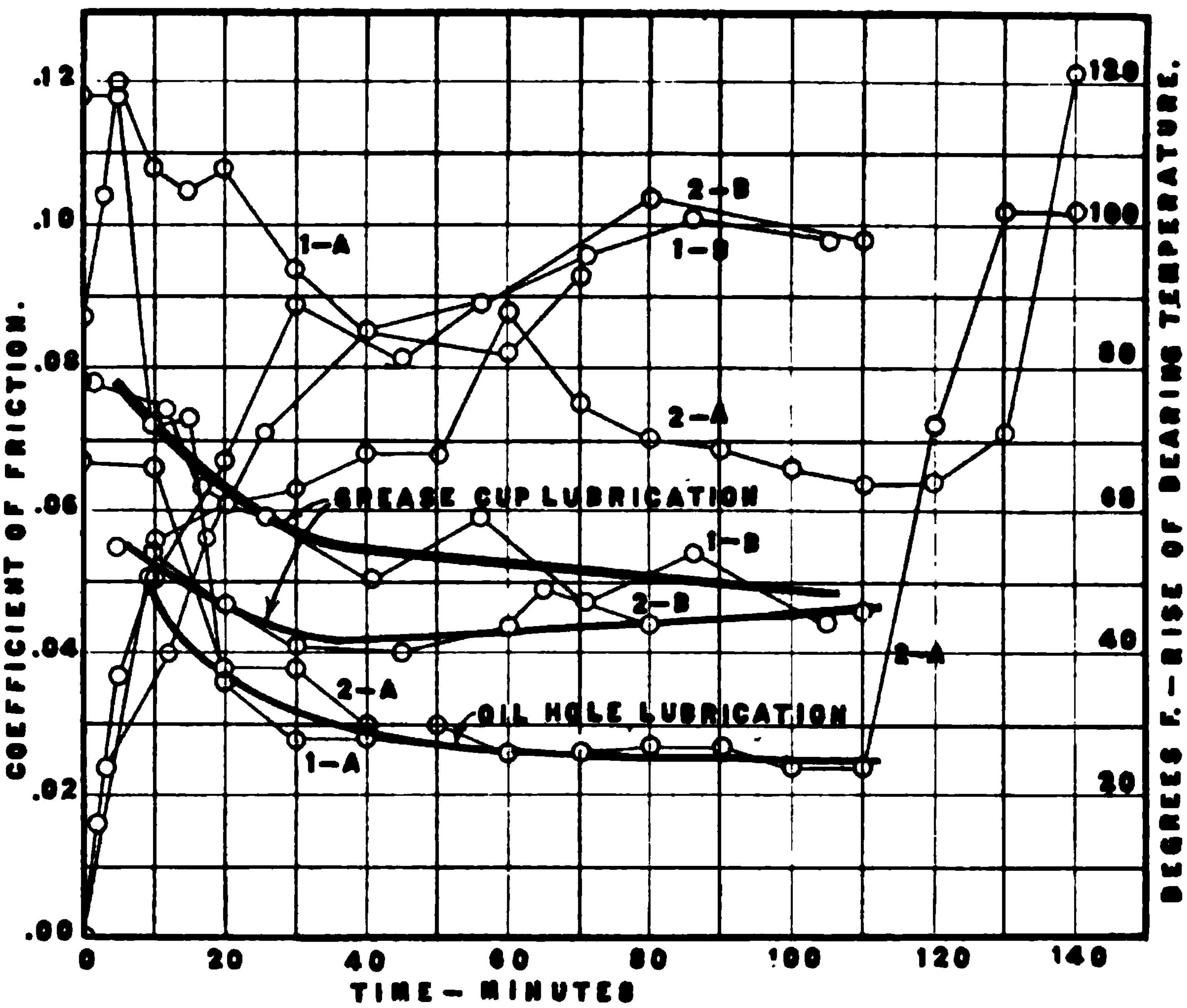


FIG. 32. SERIES C. GREASE NO. 4.

TABLE NO. 17.

TEST SERIES C, GREASE NO. 5.

Comparison of oil hole lubrication with compression grease cup, hand operated.

Load on the bearing, 114 pounds per sq. inch.

Oil hole lubrication. See fig. 33, curves a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
0	131	54	.074
2.5	134	57	.073
5	143	66	.073
7.5	145	68	.067
10	148	71	.038
12.5	160	83	.169
15	171	94	.136
17.5	176	99	.068
22.5	196	119	.191

This grease gave very poor lubrication.

Grease cup lubrication. See fig. 33, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b.			
0	103	27	.071
2	109	33	.071
7	122	46	.069
15	146	70	.047
25	150	74	.034
35	146	70	.025
45	158	82	.037
55	160	84	.037
60	163	87	.045
Second run, curves 2b.			
0	93	18	.171
5	136	61	.099
10	142	67	.066
20	160	85	.046
35	167	92	.042

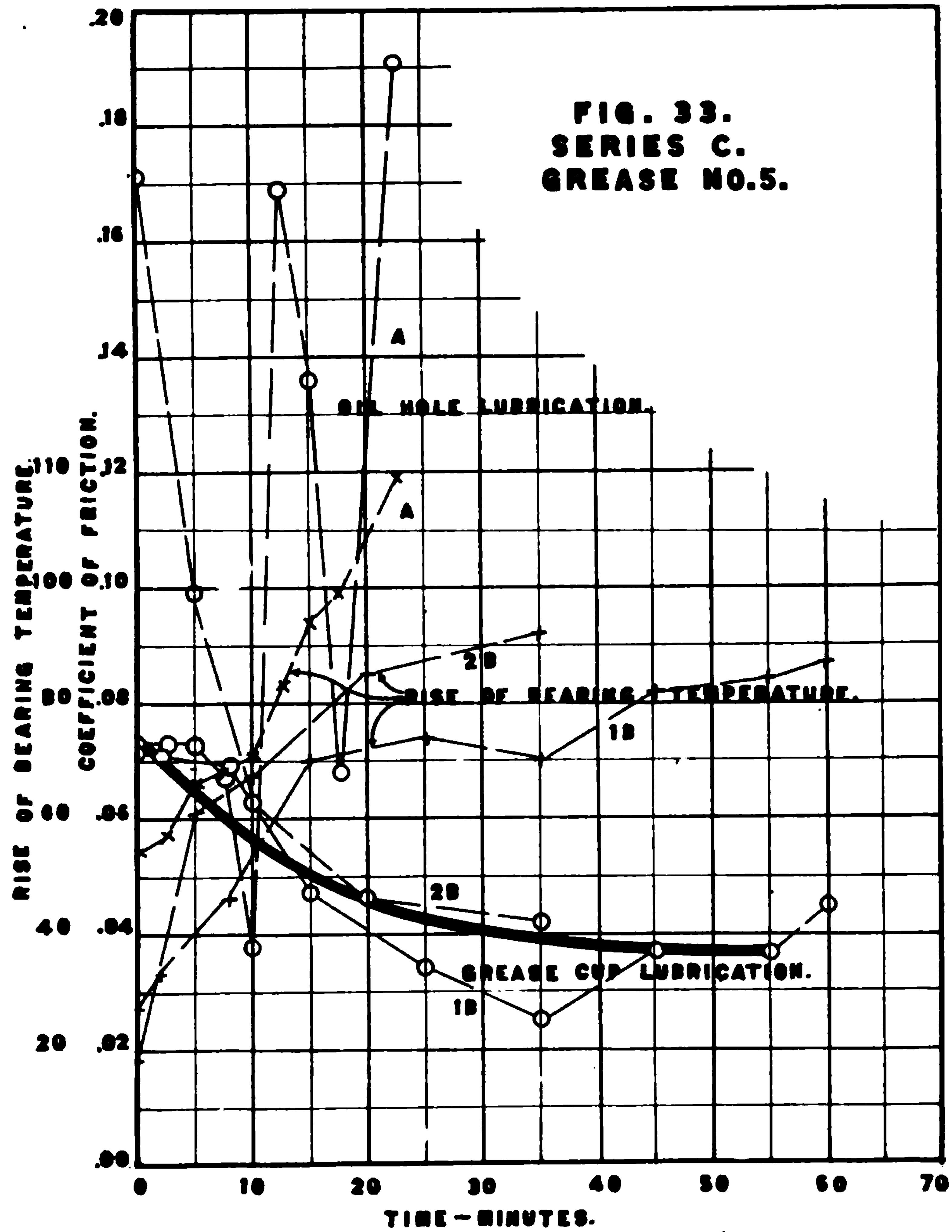


FIG. 33.
SERIES C.
GREASE NO.5.
OIL HOLE LUBRICATION.
RISE OF BEARING TEMPERATURE.
GREASE CUP LUBRICATION.
A
A
2B
1B
2B
1B
RISE OF BEARING TEMPERATURE.
COEFFICIENT OF FRICTION.
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
.00
110
100
80
60
40
20
0
10
20
30
40
50
60
70
TIME—MINUTES.

TABLE NO. 18.

TEST SERIES C, GREASE NO. 6.

Oil hole lubrication. See fig. 34, curves 1a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
0	114	34	.084
3	140	60	.067
5	151	71	.033
8	166	86	.117
13	178	98	.124
18	190	110	.091
23	200	120	.108

Lubrication failed because grease would not flow into the bearing.

Grease cup lubrication. See fig. 34, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b.			
0	84	0	.064
2	98	14	.064
5	114	30	.044
10	125	41	.051
14	122	38	.052
34	136	52	.032
40	137	53	.029
50	135	51	.034
60	153	69	.034
Second run, curves 2b.			
0	80	0	.080
2	90	8	.080
5	110	28	.030
10	124	42	.042.
20	134	52	.041
30	136	54	.032
60	142	59	.031
80	143	60	.030

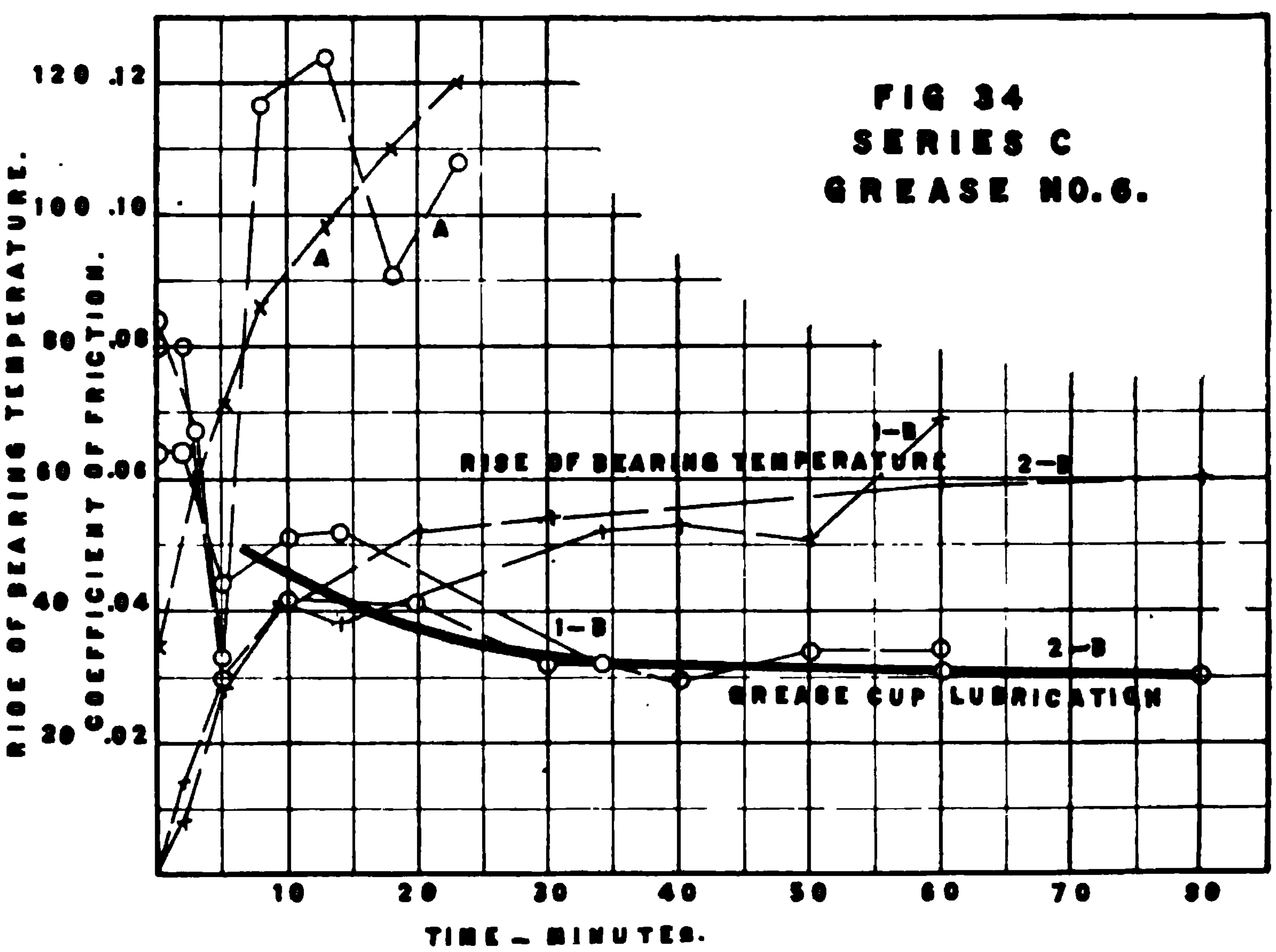


FIG 34
SERIES C
GREASE NO.6.

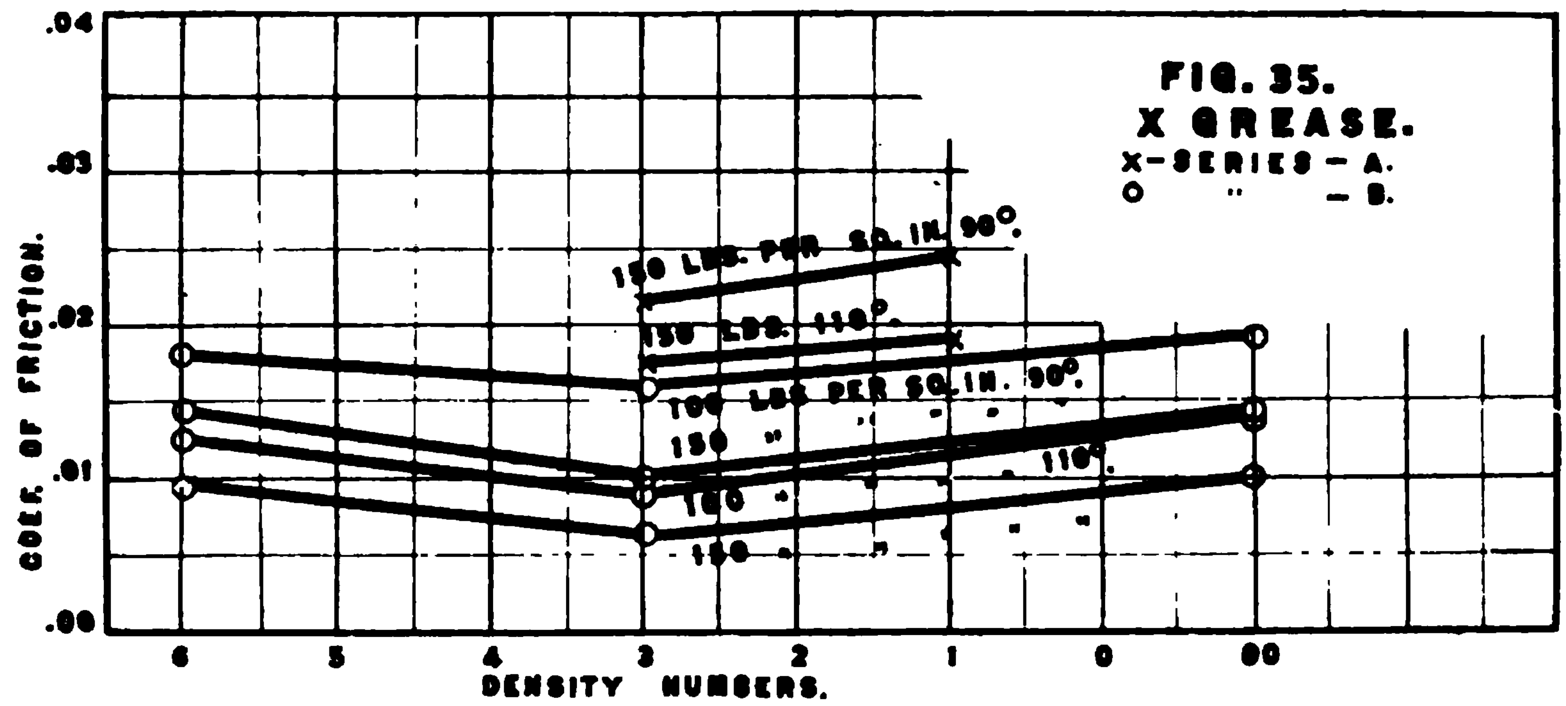


FIG. 35.
X GREASE.
X-SERIES - A.
O " - B.
150 LBS. PER SQ. IN. 90°.
150 LBS. 110°.
100 LBS PER SQ. IN. 90°.
150 "
100 "
150 "
110°.
COEF. OF FRICTION.
.04
.03
.02
.01
.00
6
5
4
3
2
1
0
00
DENSITY NUMBERS.

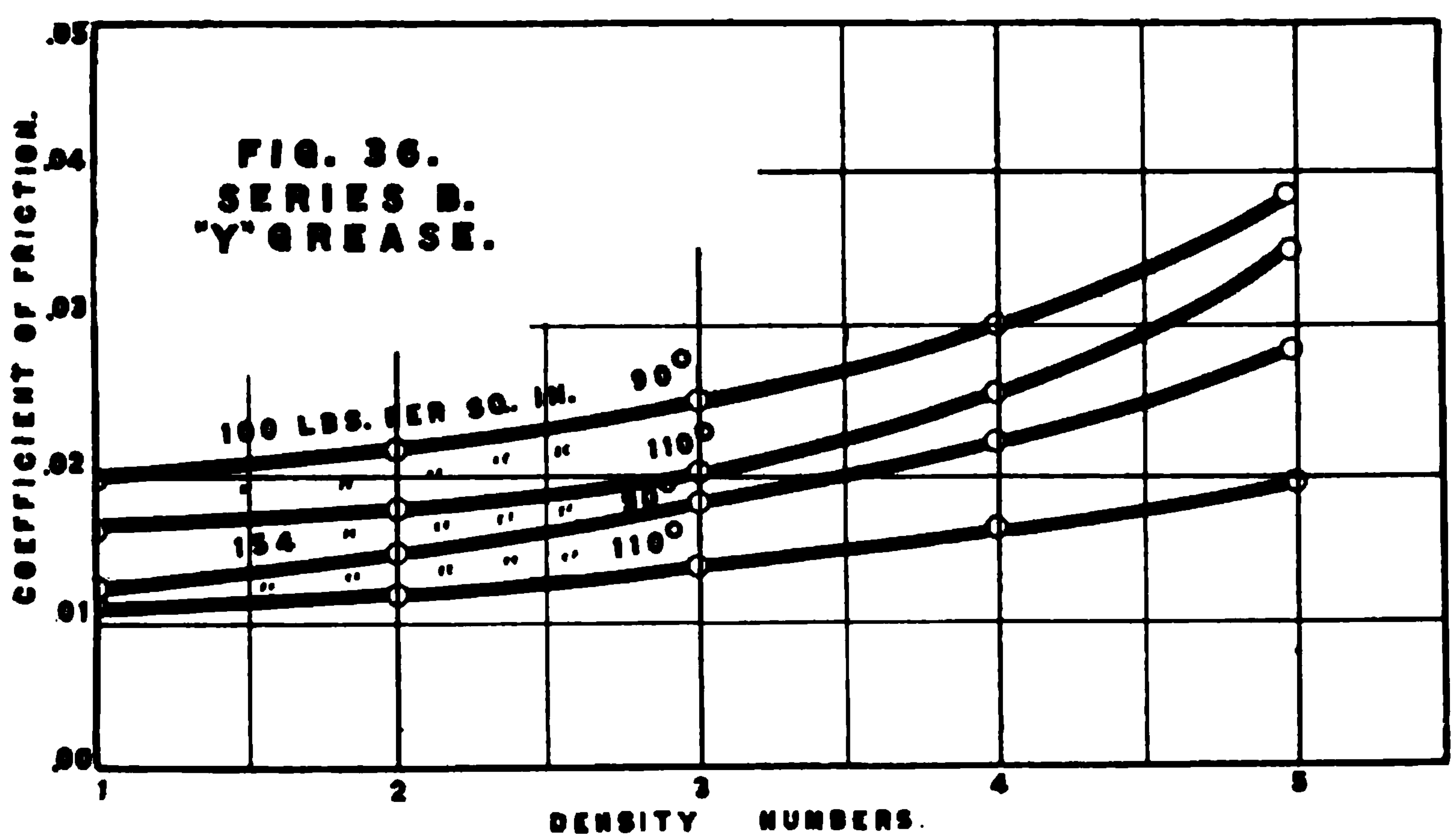
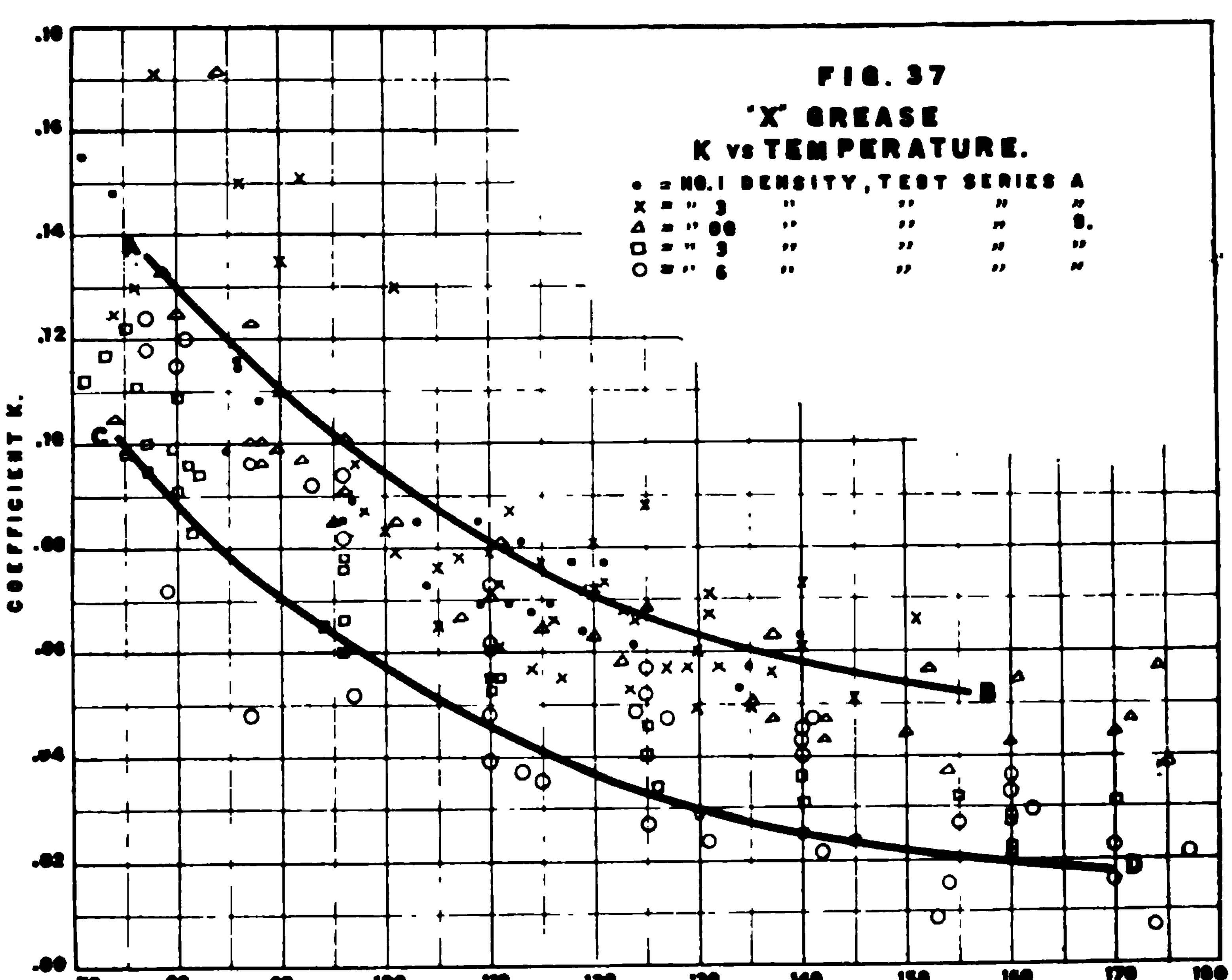


FIG. 36.
SERIES B.
"Y" GREASE.
100 LBS. PER SQ. IN. 90°
110°
154 "
110°
COEFFICIENT OF FRICTION.
.05
.04
.03
.02
.01
.00
1
2
3
4
5
DENSITY NUMBERS.

An effort was made to determine the relation between the speed of journal and the coefficient of friction. In his tests upon lubricating oils, Beauchamp Tower showed that for a given oil tested at a constant temperature, the coefficient of friction where there was perfect lubrication varied directly as the square root of the surface speed of the journals and inversely as the pressure per square inch of projected area. That is;

$$\phi = K\frac{\sqrt{S}}{w}$$

S = surface speed of journal, feet per minute.
w = load on bearing, pounds per square inch of projected area.
K = a coefficient having different values for different lubricants, and for the same lubricant at different temperatures. From the observed values of S, w, and ϕ, in the tests of series A and B, the values of K were computed by substituting in the above equation, and were plotted against the corresponding temperature of the bearing. Figs. 37 and 38 show the results of these plots for the X and Y greases respectively. Greases of different densities and series are distinguished by different forms of mark, so that the table from which each point came may be identified. Curves are drawn bounding the areas above and below, and representing the extreme values of K. These curves are designated for convenience or reference, the upper curves, AB; the lower ones, CD. It will be noticed



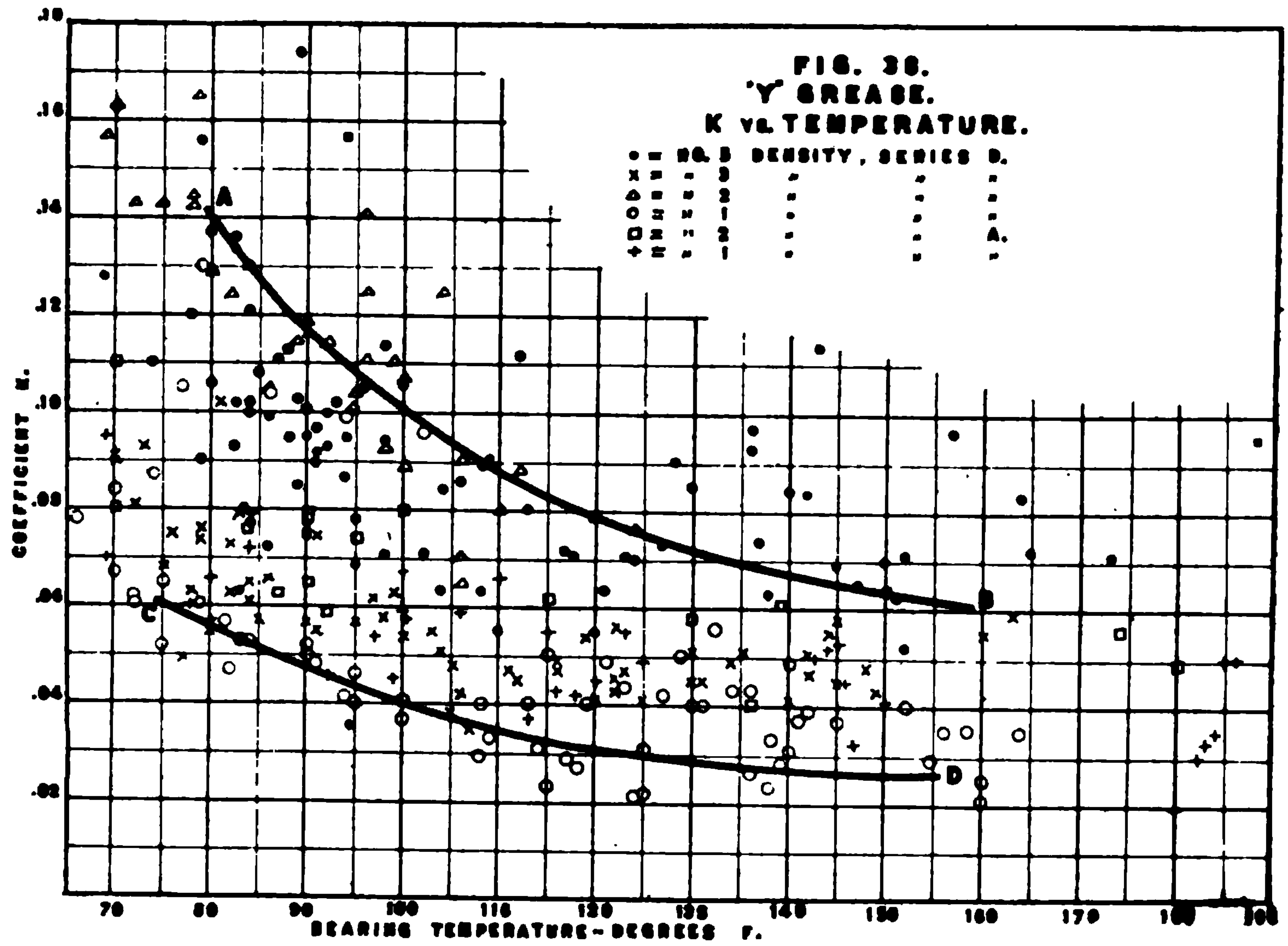


FIG. 38.
'Y' GREASE.
K vs. TEMPERATURE.

that the plots for the denser greases, in general, lie towards the upper curves CD; and the softer ones nearer the curves AB.

It was desired to find the relation between **K** and the bearing temperature, expressed in the form of an equation which might be of general application. For each of the four curves the points were replotted on logarithmic cross section paper, fig. 39. It appears from an inspection of the figure that **K** may be expressed in terms of the temperature by an equation of the form,

$$K = \frac{M}{t^n}$$

M = a constant.
t = bearing temperature, degrees F.
n = an exponent.

The following values of these numbers are found from the logarithmic plots.

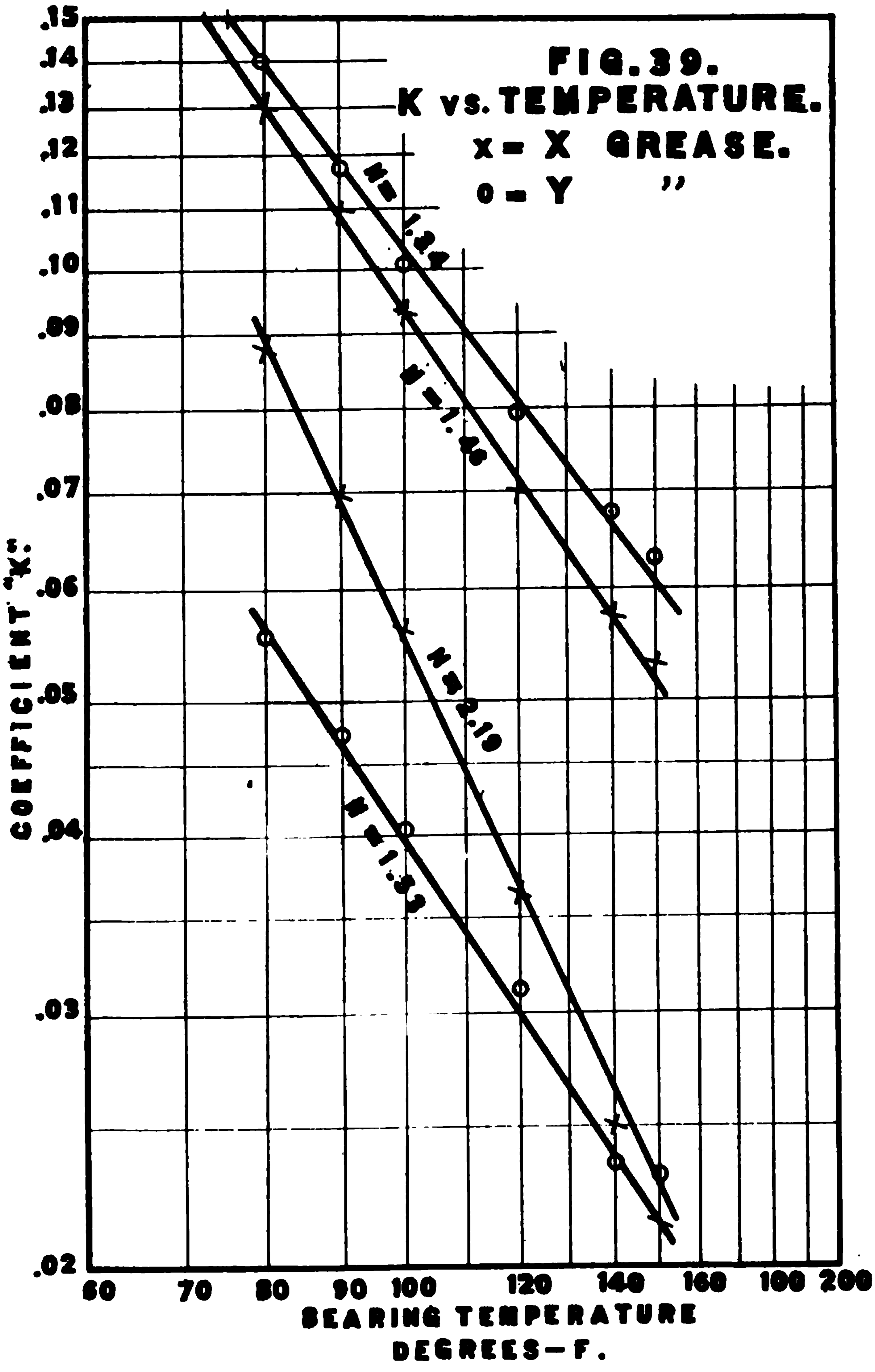
$$\text{X greases, curve, AB, } K = \frac{78}{t^{1.46}}$$

$$\text{X greases, curve, CD, } K = \frac{1370}{t^{2.19}}$$

$$\text{Y greases, curve, AB, } K = \frac{49}{t^{1.34}}.$$

$$\text{Y greases, curve, CD, } K = \frac{42}{t^{1.53}}.$$

FIG. 39.


K VS. TEMPERATURE.
X = X GREASE.
O = Y "
N=1.87
N=1.46
N=2.19
N=1.33
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
COEFFICIENT "K"
60
70
80
90
100
120
140
160
180
200
BEARING TEMPERATURE
DEGREES—F.

Lubricating oils are compared by means of certain physical tests; prominent among these is the test for viscosity. The viscosity of an oil is determined by means of a viscosimeter, several forms of which are in common use. A common form consists of a vessel to contain the oil, surrounded by a space which may be filled with water for the purpose of controlling the temperature. At the bottom of the vessel is a nozzle, through which a measured quantity of oil is permitted to flow. The viscosity is proportional to the time required for this quantity to flow through the nozzle.

It seemed to the writer that a similar scheme might be employed for the purpose of comparing greases as to their consistency, or density. As grease is a solid and therefore will not flow of itself, some compulsion must obviously be used to force the grease through the nozzle. After some preliminary experimentation, the apparatus shown in fig. 40 was constructed. This consisted of an ordinary grease cup supported upon an iron framework. A plunger was made to fit the cup closely. To insure perfect freedom of motion, the plunger was made slightly spherical. The plunger rod was carried through a guide, and supported weights placed upon its upper end. A scale graduated in twentieths of an inch was scribed on the rod, so that the time of descent over a measured distance might be noted. A nozzle of about $\frac{1}{4}''$ diameter was placed in the bottom of the cup.

Experiments with this instrument gave results that were, to the writer, decidedly surprising. It was found that the density of a given grease, as indicated by this means, is a very variable quality. Successive passages of the same grease gave constantly decreasing lengths of time for the same distance. The grease became softer and more fluid by the process of forcing it through the nozzle. This was particularly true of the harder greases. After several passages, the grease became oily in appearance. The change may be due to a more thorough mixing of the ingredients composing the grease.

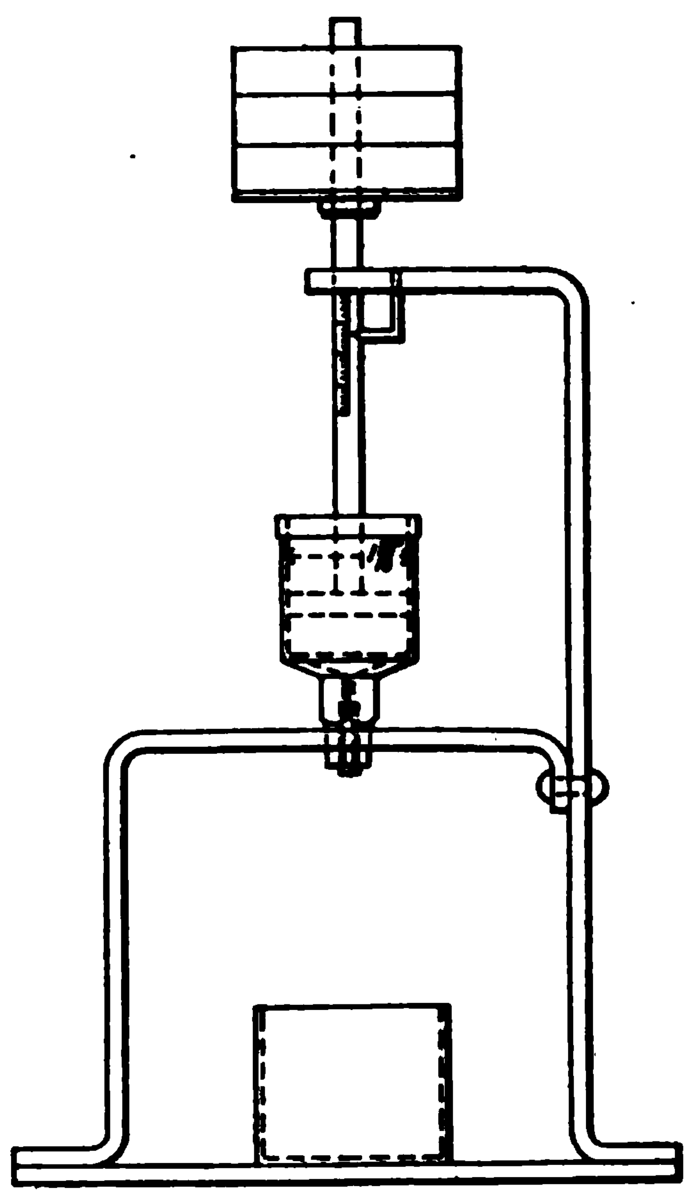


Fig. 40. Viscosity Apparatus.

The results of a number of tests of grease with this instrument are given below.

DENSITY TEST, X GREASE, No. 1 DENSITY

The same grease sample was passed repeatedly through the nozzle. The weight on the plunger was 20 lb.; temperature of grease, 71 deg. F.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Seconds to descend 1 in.	3750	235	95	66.2	57.4	36	27.2	23	19	19	16	24	14

The time became nearly constant after eight passages; the mean of Nos. 9, 10, 11, 12, 13 is 18.2 seconds.

A second test was made several days later, on the same grease sample as the preceding; load on plunger, 20 lb.; temperature of grease, 68 to 72 deg. F.

No.	1	2	3	4	5	
Seconds to descend 1 in.	17	12.6	14.2	13.8	14	mean time of last four, 13.6

The load was changed to 10 lb. and continued on the same grease sample as above; temperature of grease, 62 to 65 deg. F.

No.	1	2	3	4	
Seconds to descend 1 in.	572	670	597	593	mean time, 608

DENSITY TEST, Y GREASE, No. 3 DENSITY

A sample of the grease was passed through the nozzle 18 successive times with weights of 20, 15 and 10 lb. The temperature of the grease was 82 deg. F. at the start, increasing to 92 deg. F. at the end.

LOAD, 20 LB.

No.	1	2	3	4	5	6	7	
Seconds to descend 1 in.	50	17.4	13	3.4(?)	6.4	6.8	5.2	mean time of last three, 6.1

LOAD, 15 LB.

No.	8	9	10	11	12	13	
Seconds to descend 1 in.	15.8	16	12	11.4	11.6	9.6	mean time of last four, 11.1

LOAD, 10 LB.

No.	14	15	16	17	18
Seconds to descend 1 in.	159	131	129.6	97.8	95

DENSITY TEST, Y GREASE, NO. 1 DENSITY

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Load, lb.	10	5	5	5	5	5	5	5	4	4	3	3	3
Seconds to descend 1 in.	3.2	23.6	31	18	27.4	25	23.8	19.8	57	59.4	273	250	267

Tests numbers 2, 3, 4, and 5 were made on successive samples of grease taken from the can. Numbers 6 and 7 were repetitions of grease that had been passed once through. Similarly, 11 and 12 were new grease, while 13 was the second passage. It will be noted that for this very thin grease, no very great change occurs with successive repetitions of the test on the same sample. The time for number 6 is almost exactly the same as the mean of the preceding four.

The consistency of grease as shown by the experiments described above becomes nearly constant after several passages through the apparatus at a constant load; but it appears that when the load is changed, the grease again requires a number of passages before coming to a constant condition of consistency. It is interesting to note the great effect produced in the time of flow of the grease by a small change in the weight. Thus, in the last test, Y grease No. 1, the time was increased about 450 per cent by decreasing the load from four to three pounds.

CONCLUSIONS

Grease lubrication compares favorably with oil where the form of bearing is such as to favor the retention of the film of lubricant, and provision is made for an ample supply to the bearing. But, as shown by the experiments of series A, oil will give better results in a bearing which is short in proportion to its diameter.

Grease of soft consistency is a much better lubricant than the harder densities of the same grease. The advantage of the softer grease is especially marked at low temperatures such as usually obtain in a well lubricated bearing.

The best method of applying grease to a bearing is by a forced feed and a constant rate of flow. This agrees with the best practice in oil lubrication, where the bearing is flooded with oil, which passes to a filter and is then used over again. The drawback in case of grease, is the problem of cleaning it after it has passed once through the bearing, so that it could be used over again.

Grease cups with spring actuated plunger are designed to give a constant flow of grease. They are far from accomplishing this purpose, however. When such a cup is full of grease, the spring is compressed to its maximum amount and the pressure upon the grease is therefore much greater than when the cup is nearly empty. Provision is made to regulate the flow by means of a small cock placed in the outlet of the cup, but this needs adjustment as the cup empties and is apt to be neglected. If the setting is right when the cup is filled the bearing will be insufficiently supplied when it is partly emptied. The experiments upon grease consistency show what a great difference in flow is produced by a small change in the pressure upon the grease. A design of cup is desirable which will deliver the grease at a constant rate from the time it is filled until it is empty.

TESTS OF LUBRICATING OILS.

The results of these tests are given in Tables Nos. 19 to 26, and in graphical form in figs. 41 to 48.

Eight oils, numbered 1 to 8, were tested. Their physical characteristics are given in the following table.

Number	Kind of Oil	Gravity, deg. Be.	Flash Point, deg. F.	Burning Point, deg. F.	
1	Liquid base cylinder oil	27	366	378	Yellow-green.
2	Engine oil	32	405	......	Light red.
3	Standard gas engine oil	25.7	419	445	Dark red.
4	Gas engine oil	28.4	386	405	Light straw
5	Gas engine oil	20.9	340	350	Dark straw.
6	Engine oil.	20	348	362	Dark yellow
7	Gas engine oil	18.9	365	380	Straw
8	Engine oil	19.4	395	405	Reddish yellow.

TABLE NO. 19.

OIL NO. 1. LIQUID BASE CYLINDER OIL. (Fig. 41.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction. Temperature of Bearing, °F.				
	81	102	121	141	159
65.6	.0196	.0143	.0086	.0068	.0049
103.1	.0155	.0095	.0065	.0037	.0030
135.7	.0126	.0060	.0039	.0047	0030
170.7	.0101	.0060	.0039	0037	.0029
204.7	.0080	.0059	.0044	.0041	.0036
239.8	.0066	.0056	.0051	.0060	.0042

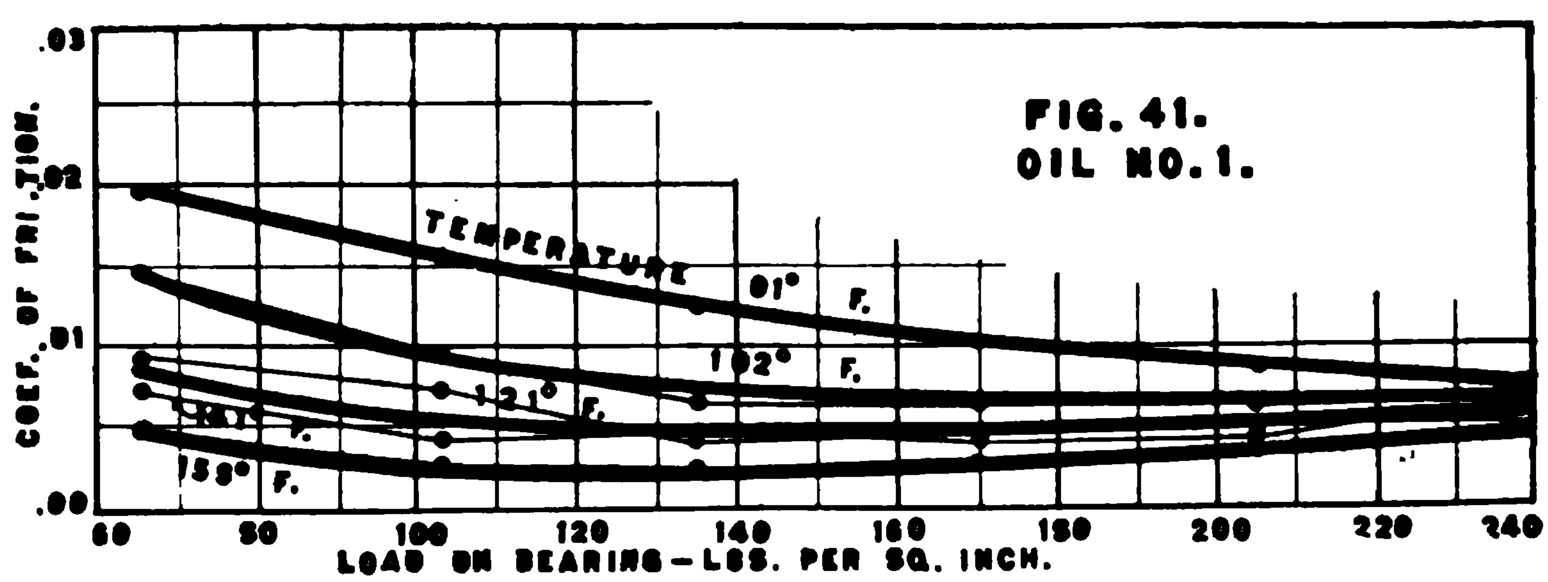


FIG. 41.
OIL NO. 1.

TABLE NO. 20.

OIL NO. 2. ENGINE OIL. (Fig. 42.)

Load on Bearing. Pounds per Square Inch.	Coefficient of Friction. Temperature of Bearing. °F. 78	100	120	142
65.6	.0235	.0191	.0125	.0083
103.1	.0183	.0175	.0110	.0073
135.7	.0149	.0116	.0084	.0059
170.7	.0128	.0091	.0055	.0059
204.7	.0111	.0075	.0056	.0052
239.8	.0072	.0071	.0045	0043

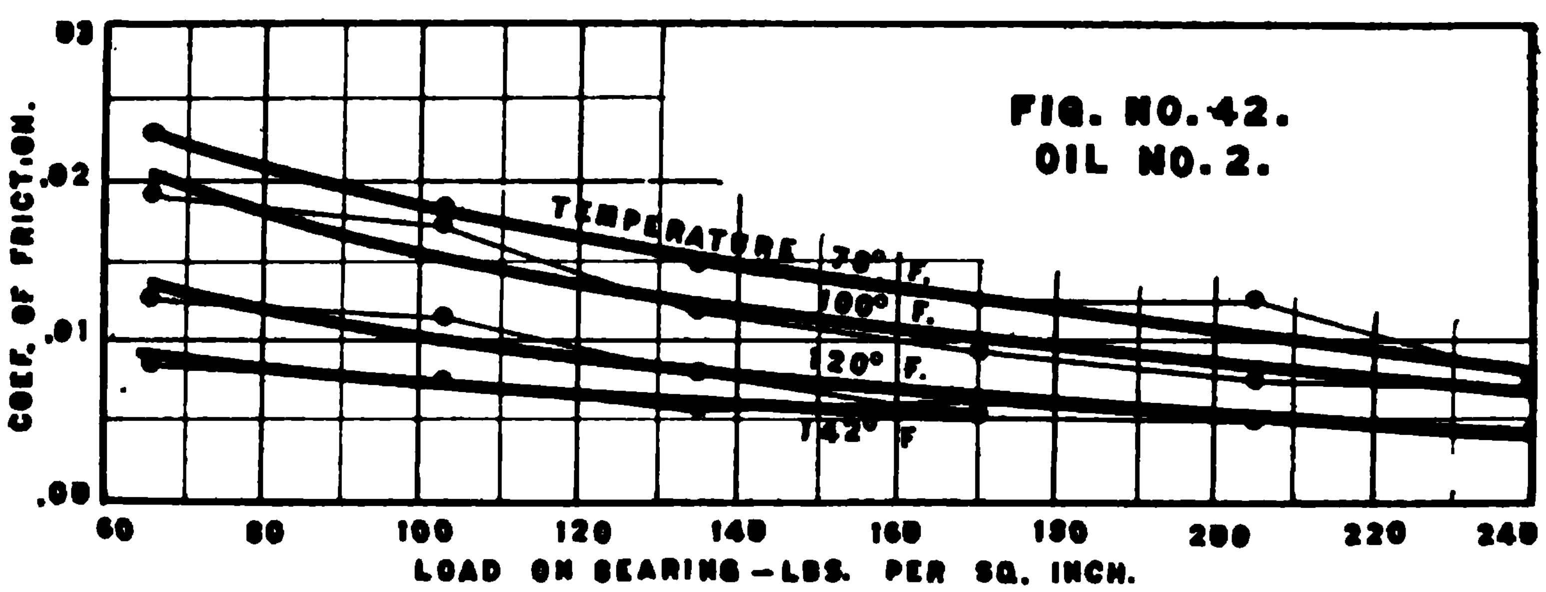


TABLE NO. 21.

OIL No. 3. GAS ENGINE OIL. (Fig. 43.)

Load on Bearing. Pounds per Square Inch.	Coefficient of Friction. Temperature of Bearing. °F. 80	101	121	140	160
65.6	.0424	.0270	.0165	.0153	.0093
103.1	.0300	.0205	.0125	.0124	.0058
135.7	.0232	.0168	.0125	.0075	.0058
170.7	.0198	.0158	.0115	.0066	.0057
204.7	.0165	.0140	.0089	.0056	.0055
239.8	.0139	,0127	.0087	.0066	.0056

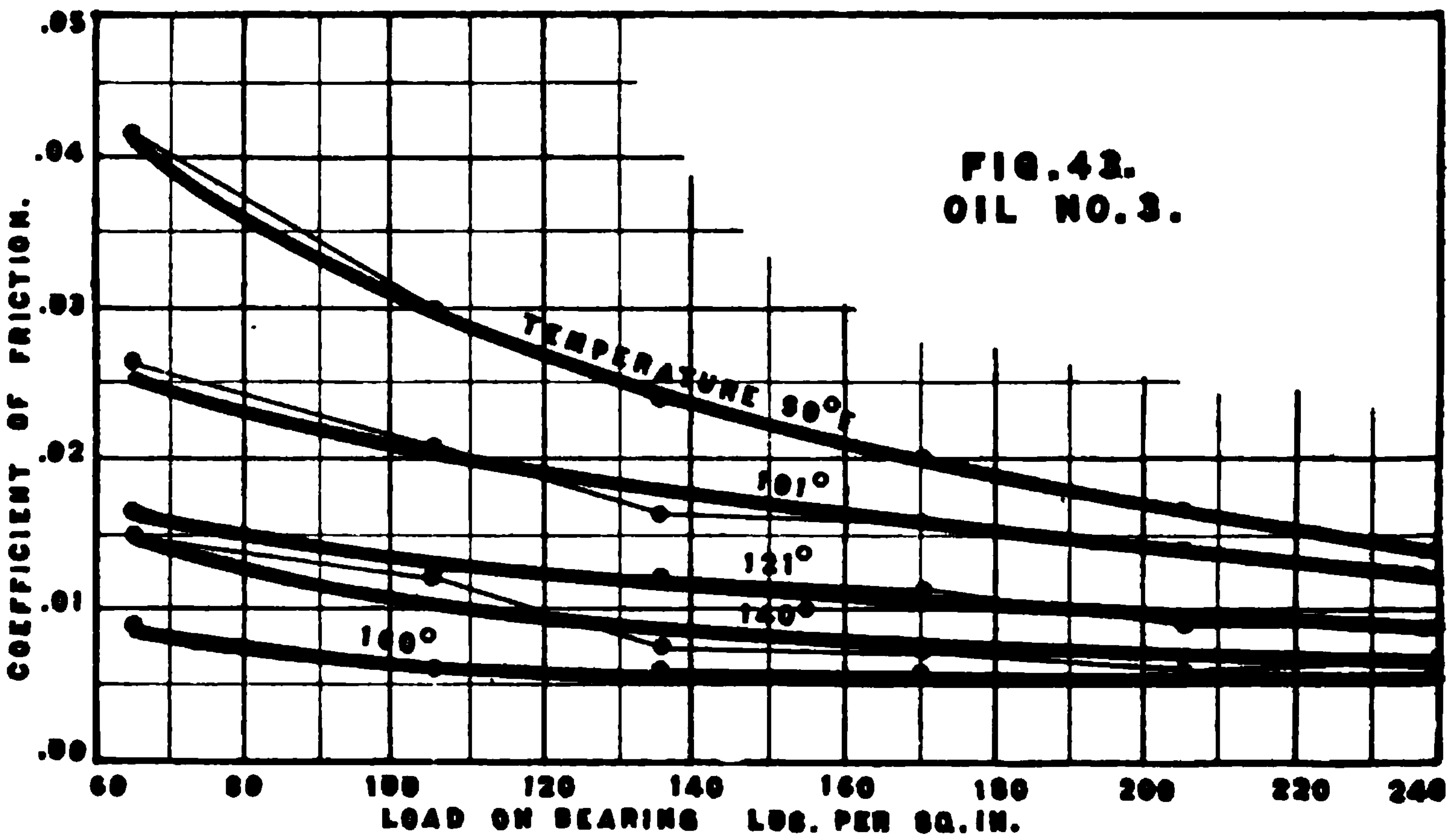


TABLE NO. 22.

OIL No. 4. GAS ENGINE OIL. (Fig. 44.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.				
	Temperature of Bearing, °F.				
	79	103	121	141	159
65.6	.0271	.0152	.0174	.0075	.0056
103.1	.0186	.0162	.0103	.0025	.0057
135.7	.0167	.0105	.0088	.0056	.0039
170.7	.0140	.0087	.0082	.0052	.0034
204.7	.0115	.0089	.0067	.0041	.0036
239.8	.0095	.0080	0051	.0040	.0044

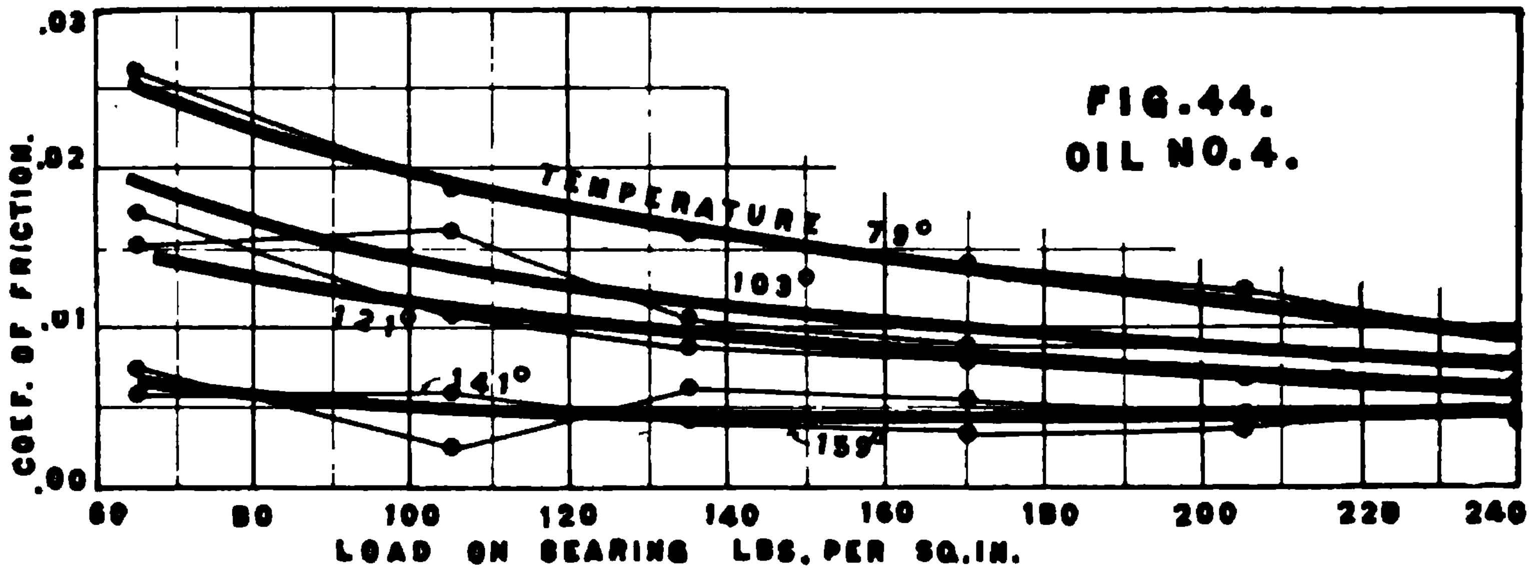


TABLE NO. 23.

OIL No. 5. GAS ENGINE OIL. (Fig. 45.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.				
	Temperature of Bearing, °F.				
	79	102	120	141	160
65.6	.0319	.0197	.0110	.0140	.0059
103.1	.0319	.0155	.0092	.0125	.0050
135.7	.0238	.0115	.0072	.0062	.0040
170.7	.0184	.0087	.0060	.0057	.0037
204.7	.0136	.0080	.0065	.0058	.0033
239.8	.0121	.0062	.0077	.0057	0024

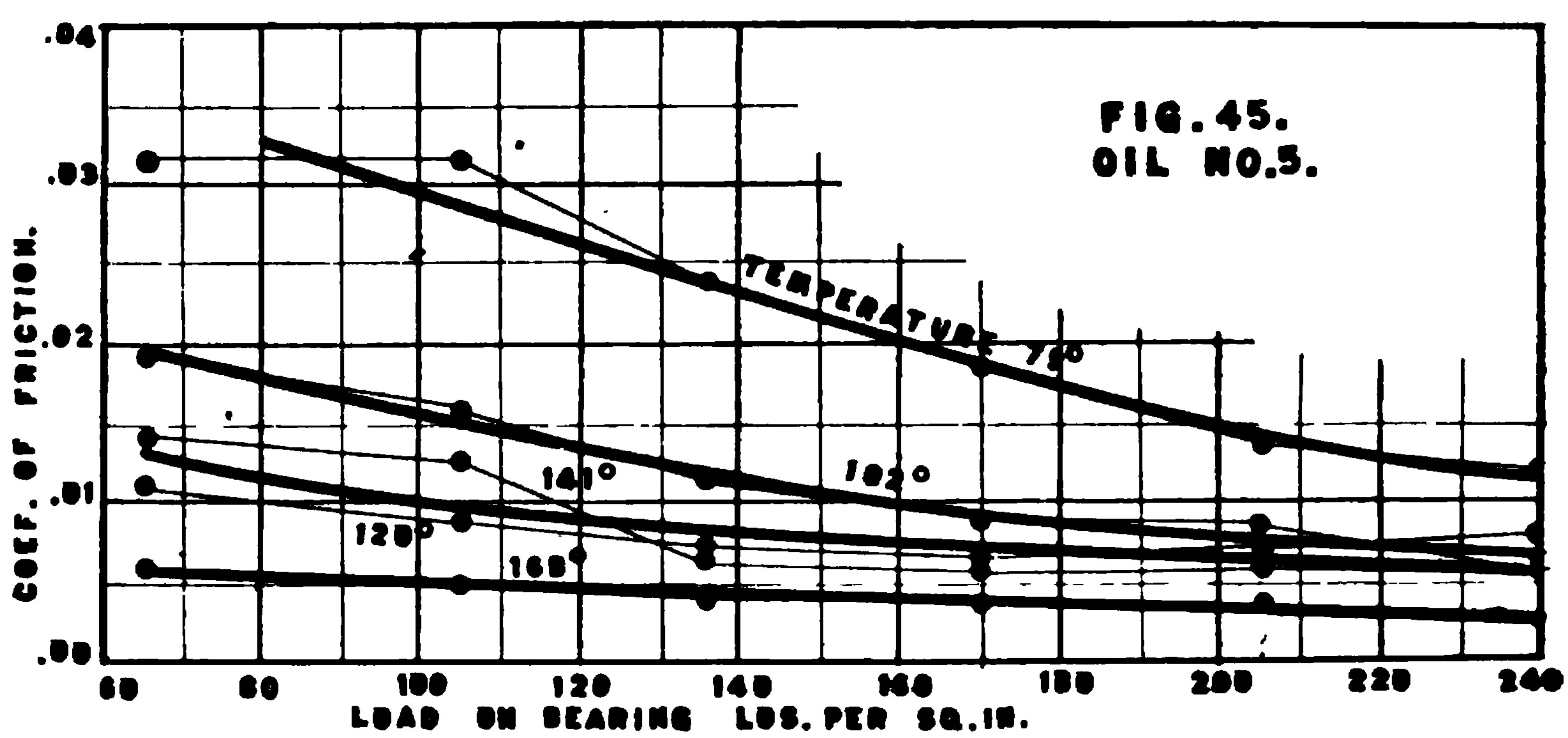


TABLE NO. 24.

OIL No. 6. ENGINE OIL (Fig. 46.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.			
	Temperature of Bearing, °F.			
	81	102	121	142
65.6	.0492	.0250	.0206	.0088
103.1	.0283	.0211	.0133	.0063
135.7	.0272	.0172	.0135	.0064
170.7	.0200	.0132	.0092	.0063
204.7	.0158	.0138	.0087	.0057
239.8	.0148	.0107	.0090	.0051

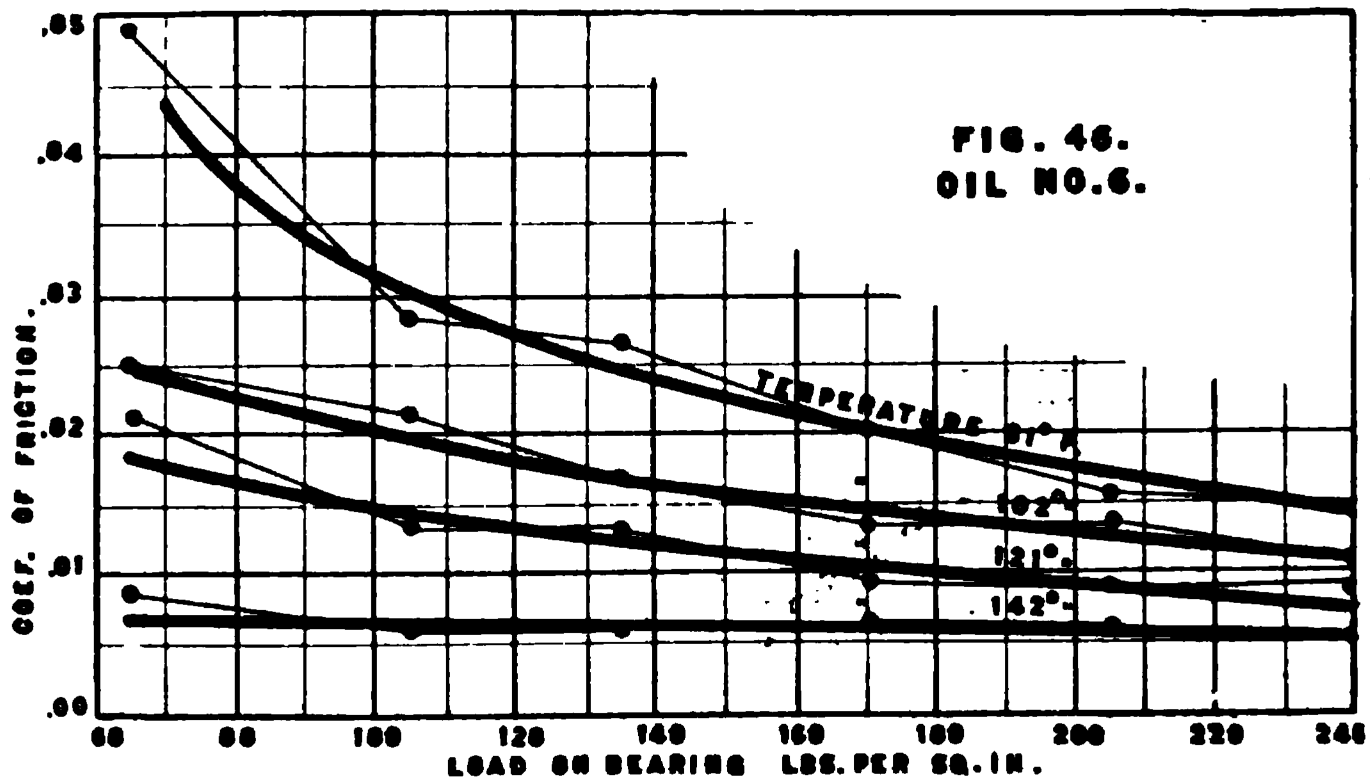


TABLE NO. 25.

OIL No. 7. GAS ENGINE OIL. (Fig. 47.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.				
	Temperature of Bearing, °F.				
	84	103	121	141	161
65.6	.0589	.0376	.0302	.0177	.0139
103.1	.0421	.0252	.0169	.0138	.0097
135.7	.0325	.0187	.0150	.0119	.0064
170.7	.0135	.0154	.0137	.0097	.0062
204.7		.0131	.0128	.0084	.0065
239.8		.0124	.0110	.0071	.0070

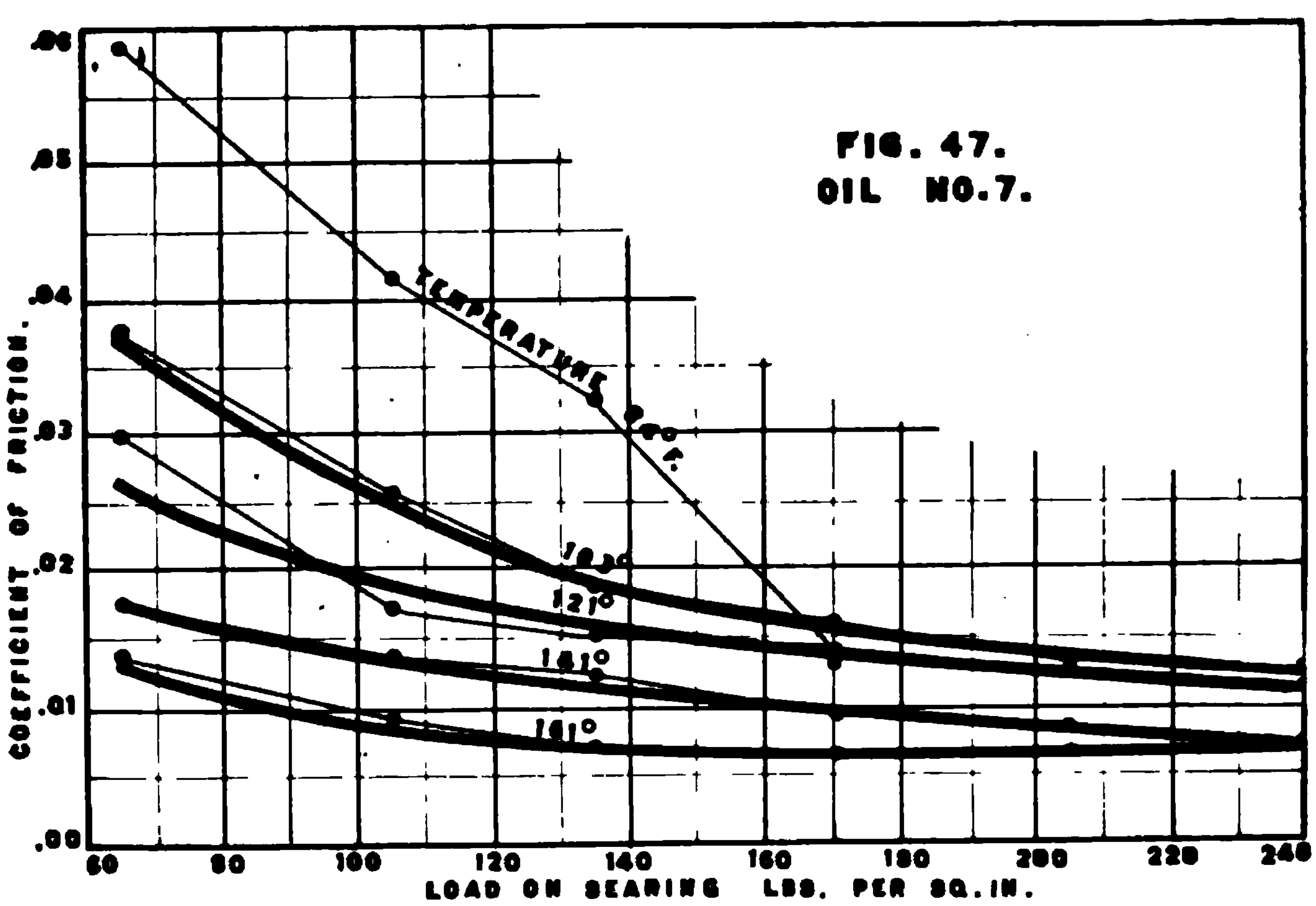
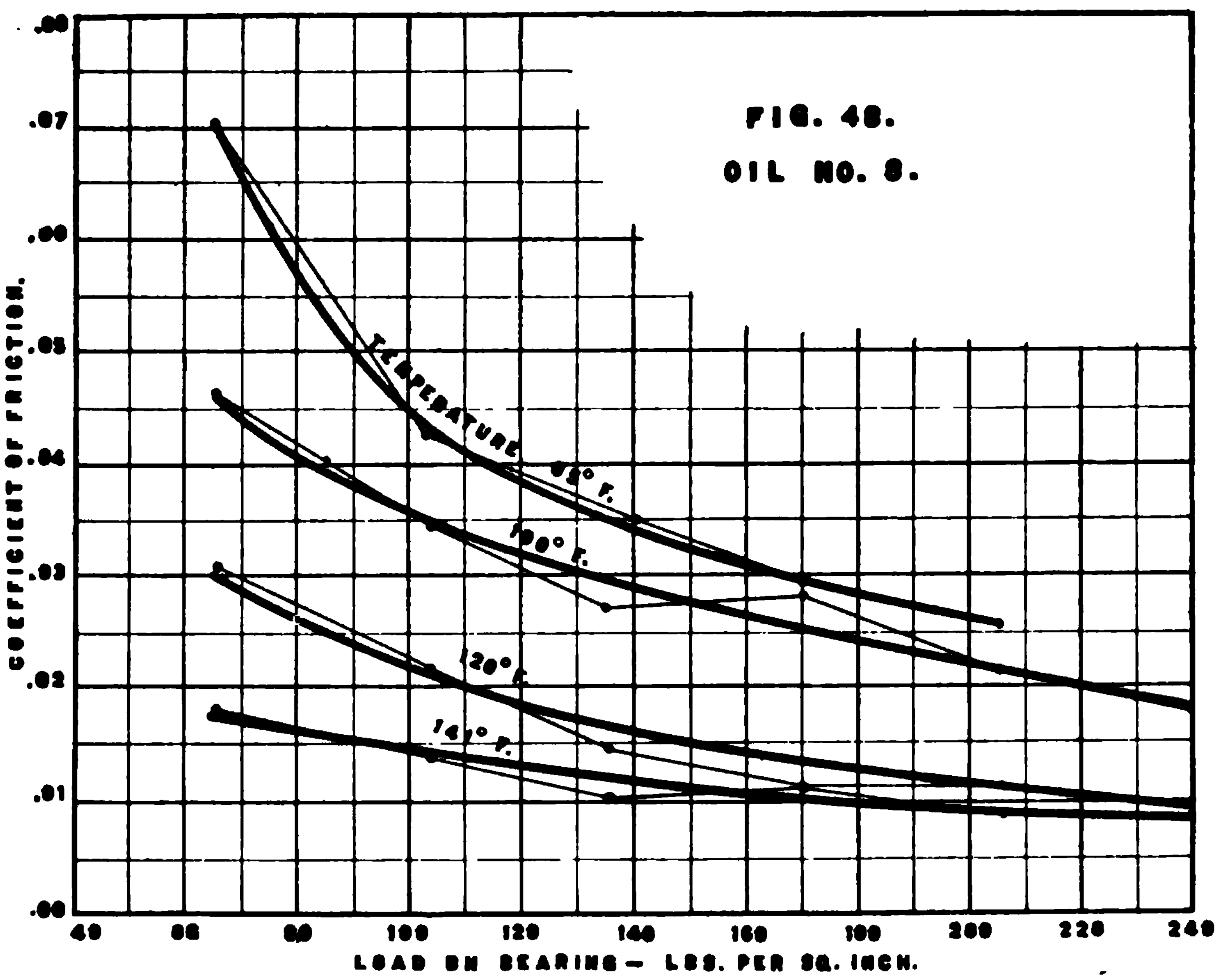


TABLE NO. 26.

OIL No. 8. ENGINE OIL. (Fig. 48.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.			
	Temperature of Bearing, °F.			
	85	102	120	141
65.6	.0706	.0463	.0306	.0183
103.1	.0427	.0345	.0217	.0136
135.7	.0363	.0266	.0146	.0103
170.7	.0294	.0289	.0113	.0111
204.7	.0253	.0213	.0112	.0093
239.8		.0180	0100	.0089



An inspection of the curves, figs. 41 to 48, shows that in general, the coefficients of friction vary directly as the specific gravities; the higher the gravity number, in degrees Baume, the less the coefficient of friction for a given load and temperature. This is especially marked in case of oils Nos. 6, 7, and 8, whose densities are not over 20 degrees Be. They give much higher friction values than any of the other, less dense, oils.

The forms of the curves showing the relation between load on the bearing and the coefficient of friction, are similar to those representing the grease tests. With increasing loads, the curves representing different temperatures tend to converge to a common point; and if the loading of the journal had been carried far enough, a point would have been reached where the curves for the higher temperatures would cross those representing the lower temperatures. A tendency in this direction is especially noticeable in case of oil No. 1.

In conclusion it may be stated that the friction test, as a guide to the selection of the best oil for a given purpose, and the elimination of the inferior oils, is not commonly employed. Experimental research by means of friction testing machines is recognized as of value for the purpose of developing the laws of friction of lubricated surfaces, and for making comparisons of the behavior of different lubricants under the same conditions. But there seems to be considerable doubt in the minds of lubrication engineers as to the value of such work as a means of determining the lubricating value of an oil in actual use. There can of course be no question but that the conditions of the test journal are ideal and quite different, as a rule, from those that obtain in a bearing in practice. The writer is of the opinion, however, that if a sufficient study were made of the question, a standard method of testing, in which the load, speed, quantity of lubricant applied, temperature, and length of time, are all carefully specified, might be devised and be of much practical assistance as an auxiliary to the other physical and chemical tests that are now commonly employed in the examination of lubricating oils.

An engine oil specification is given below, under which engine oil for general purposes is purchased by the St. Louis Water Works. This engine oil must be suitable for crank case oil, in engines having a splash system of lubrication, as well as for lubrication of the main bearings of engines and other general purposes. The qualifications laid down in the first paragraph, as to emulsifiable matter, etc., are therefore of the first importance. The oil must not emulsify when it becomes mixed with water in the crank case of an engine; and a special laboratory examination is necessary to see that the oil supplied possesses this qualification.

SPECIFICATIONS FOR ENGINE OIL NO. 1.

Engine Oil No. 1 shall be the filtered product obtained from the refinement of pure mineral crude oil without the subsequent addition of any other substance foreign to this distillation. It must be absolutely clear, free from water, tarry, emulsifiable or suspended matter and shall be absolutely neutral in its reaction.

The oil shall possess the following characteristics:

1. Its specific gravity shall not be less than 25.5 and not more than 26 degrees Be. at 60 degrees F.
2. It must not flash below 370 degrees F. when tested in Pensky-Martin closed flash apparatus.
3. It must not burn below 440 degrees F. in the open cup of the Pensky-Martin apparatus.
4. Its specific viscosity shall not be less than 12 degrees Engler at 70 degrees F.
5. When heated for seven hours at 150 degrees F. it shall show a loss of not more than 1% by weight; and when heated for two hours at 350 degrees F. it shall show a loss of not more than 14% by weight. There shall be no deposit of carbonaceous matter resulting from either of these tests.

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EDITED BY

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Associate Professor of Mechanical Engineering.

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ENGINEERING EXPERIMENT STATION SERIES 14

A STUDY OF THE EFFECTS OF HEAT ON MISSOURI GRANITES

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COLUMBIA, MISSOURI
September, 1914

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and four research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

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A STUDY OF THE EFFECTS OF HEAT ON MISSOURI GRANITES

INTRODUCTION

Experience has shown that when certain of our building and ornamental stones are subjected to high temperatures, as in the burning of a building, they are very seriously damaged or are entirely destroyed. The extent to which each is damaged depends upon the mineralogical and chemical composition and upon the physical properties of the rock.

The studies which are described in this bulletin were undertaken with the object of determining the factors involved in the changes during which a given stone is damaged. Since all rocks consist of one mineral or an aggregate of minerals, the disaggregation of the rock under high temperatures should depend upon the physical properties of each of the minerals in the rock and upon their relations to each other. The best means of studying the internal structure and changes in a rock are with a petrographic microscope, and these investigations include a careful microscopic examination of the rocks studied.

For our work we used Missouri granites because they are usually very badly damaged in a fire. Furthermore their mineralogy is more complex than that of most of the common building stones and this gives a wider field for study. Another reason for using this stone is that there is no definite proof as to the cause of the disaggregation of granites under conditions of high temperatures and it was hoped that evidence bearing upon this might be obtained. As the results of the work show, we have been generally successful in getting this evidence.

The experiments consisted of heating prepared cubes of the granite to a very high temperature, cooling them under various conditions and determining their strength. The material was carefully examined before and after heating and the effect noted. Thin sections of the fresh rock and the heated rock were studied with the microscope and any changes in the minerals of the rock were noted. By this method we were able to definitely locate the cause of the disaggregation.

A general series of tests were run at various temperatures in order to determine, if possible, the point at which the granite first began to weaken. The major part of the tests were upon sets of cubes, one part of the set being heated to 500° C (about 950° F) and

the other to 750° C (about 1400° F). These temperatures were chosen because they are closely related to certain physical properties of one of the constituent minerals of the granite. This mineral was regarded as the most important in causing the damage, as will be discussed later.

These results are of importance in showing, not only that granites should not be used where they might be exposed to high temperatures in a fire, but that in such a case they will not support a very heavy load.

The writer has been ably assisted in this work by Mr. L. M. Neumann, Research Assistant in the Engineering Experiment Station of the University of Missouri. He did all the heating and testing of the strength of the materials and wrote the descriptions of the physical tests.

PREVIOUS WORK

Rock has been one of man's most important building materials ever since he first began to provide shelter for himself. Since most buildings are constructed of stone and wood, and the latter, and most of man's household goods are very inflammable, fires are of all too frequent occurrence. Fire resisting materials were sought for long ago, and experiments as to the fire resisting qualities of various rocks used were begun about eighty or ninety years ago. These early tests usually consisted in heating various stones to a high temperature (either in a specially constructed furnace or in a temporary structure built for that purpose), and in noting the effect upon them. As water is generally used at a fire, the heated stones were treated to a sudden bath by plunging them into water or throwing a stream of water upon them and noting the results.

Thus it was early learned that while granite is a very durable stone and retains a polish longer than most common building stones, it was less resistant to fire than limestone or sandstone.

Some of the more important experimenters along these lines may be mentioned briefly.

H. A. Cutting was probably the first to test a series of various building stones with high temperatures.[1] He found that granite became worthless at 1000° F. He ranked the stones he tested as follows; (the most resistant first), marble, limestone, sandstone, and granite.

J. A. Dodge, about the same time, tested a series of building stones for the Minnesota Geological Survey.[2] He heated them to a dull red in a muffle furnace and plunged them into water. His results are

1. Cutting. H. A., Am. Jour. Sc. series 3, 21: 410: 1881.
2. Dodge, J. A., Minn. Geol. Sur. Vol. 1: 168.

not given comparatively, but they indicate that coarse grained rocks are more injured by high heating than fine grained ones. Most of his tests were upon syenites.

That fine grained rocks are more resistant is also shown by the results of Jackson on some California granites.[3]

E. R. Buckley carried out a rather extensive series of tests upon Wisconsin building stones, and later, while State Geologist of Missouri carried out similar tests on Missouri building stones.[4] Rocks of even grain and simple mineralogical composition were found to be the most resistant, and fine grained rocks were far more so than coarse grained, the latter being a very poor fire resisting rock. Most of the granites could easily be crumbled in the hand.

Probably the most complete series of tests that has been made up to date are those of W. E. McCourt for the New Jersey Geological Survey.[5] His tests were made on three-inch cubes, some of which were heated in a muffle furnace to 550° C. (1022° F.), and were cooled in air and water, and others were heated to 850° C. (1562° F.) and cooled the same way, while still others were heated in an open flame. He regards the last temperature as about that of a fire. His conclusions were similar to those of the preceding men. The coarse grained rocks were more damaged than the fine, and sudden cooling in a stream of water was very injurious, usually destroying the stone. The granites were ranked last at the lower temperature, and the coarse grained ones nearly last at the higher temperature; the fine grained being more resistant.

R. L. Humphrey heated some building blocks of granite to a temperature of about 1700° F. for about two hours, then turned a stream of cold water upon them while still hot.[6] The granite spalled off over one-fourth the area exposed to the flame to a depth of one to one and one-half inches. After their removal from the panel where they were heated, it was found that all the blocks were badly cracked and broken up into fragments about four by eight inches. The major cracks were across the stones and in a plane parallel to the face exposed to the flames. All were easily broken.

While the experiments carried out by these men are of interest in showing the relative durability of the stones, none of them carried the studies far enough to find out the cause of the disruption of the granite, although suggestions were made by some of them. Likewise no strength determinations were made before and after heating. Buckley in both his Wisconsin and Missouri reports recognizes that such

3. Jackson, 8th Ann. Rep. State Min. of Calif., 1888.
4. Buckley, E. R., "Building Stones of Wisconsin," Bull. IV. Wis. Geol. and Nat. Hist. Survey, 72 and 385.
Buckley, E. R., and Buehler, H. A., Mo. bur. Geol. and Mines, 11 (2): 49.
5. McCourt, W. E., Ann. Rep. State Geol. 1906: 19-77.
6. Humphrey, R. L., Bull. 370, U. S. G. S.

tests would be of value. Many of the earlier experimenters subjected the rocks they were testing to conditions which were really far more severe than the stone would probably ever undergo, their results showing that the stone was almost completely destroyed. After the tests they were often able to crush the rock in the hand, hence they did not recognize the need of testing the strength.

VIEWS HELD AS THE CAUSE OF THE DISAGGREGATION OF GRANITE

Two views are held as to the cause of the disaggregation of granite. Both are mentioned in the literature on granite. The one which seems to be regarded as most important, at least by some of our leading geologists, is as follows. The quartz in granite has long been known to contain cavities which are very minute, and are usually more or less filled with a gas, or liquid, or both, and more rarely with some solid. Water is the most common in them, but carbon dioxide has frequently been found, as well as a few other substances. On heating the granite, this water is thought to be converted into a gaseous state, and, as at high temperatures its expansive force is very great, it bursts open the small cell it is in and thus fractures the mineral and, of course, the rock. These cavities are found only in the quartz and not at all in the feldspar or the other minerals of the granite.

The other view holds that the expansion of the minerals, when highly heated, disrupts the rock. The major mineral constituents are known to have different rates of expansion and this would produce stresses which would differ in different directions in the rock and would thus cause its disruption. What may be regarded as merely a larger application of this view is held by some men. According to them the outer portion of the rock on being highly heated expands more than the cooler interior and thus tends to pull away from it. If water were thrown upon this highly heated outer portion, it would contract very suddenly and this shell would scale off from the rock. As stated above, we believe we have definite proof as to which one of these views is the more correct and these proofs will be presented in a later chapter.

CHAPTER I

DESCRIPTION OF THE GRANITES TESTED

The material for our tests was obtained from the various quarries in southeastern Missouri. There were four quarries in more or less active operation at the time of our visits to them. At least one set of six cubes each was obtained from each of these quarries and a set was also obtained from the Gilsonite quarry near Knoblick, Missouri, because of its marked difference from the other granites of Missouri. This quarry was not operating at the time of our visit. Several sets were made of the material from the A. J. Sheahan Granite Company's quarry at Graniteville, Missouri. This company is one of the most important producers of granite for building material at the present time. The Schneider Granite Company's quarry is located about one quarter of a mile north of Graniteville. Two sets were obtained here, one from their building material, and the other from their paving block material.

Milne and Gordon, and the Missouri Granite Company are operating quarries near Knoblick, Missouri. The quarry of the former is about two miles west of Knoblick, and produces monumental and building material. The Missouri Granite Company's quarry is about three miles southwest of Knoblick. They produce mainly crushed granite and paving blocks. The material was prepared for testing by A. Allen at Graniteville.

Sheahan Granite Company's Quarry.—This granite is a pinkish red to dark red rock, varying from medium to coarse-grained, with an occasional phenocryst of feldspar an inch or so in length. It consists of feldspar and quartz with minor amounts of biotite (partly altered to chlorite), muscovite, magnetite, hematite and several grains of pyrite. A grain of fluorite may be seen occasionally. An estimate of the relative proportions of the major constituents made according to the Rosiwal method gave 31.3 per cent for quartz and 68.7 per cent for feldspar.[7] All other constituents were less than two per cent and were not measured in getting the percentage of the quartz and feldspar.

The feldspar varies from pink to dark red in color. The crystals average about one-fourth of an inch in diameter, with an occasional phenocryst up to one and a quarter inches long. Zonal banding

7. Bulletin 313, U. S. Geol. Sur. p. 173.

occurs in some of the larger crystals. Considerable chlorite has developed in some of the feldspar, giving it a marked green color. The phenocrysts very frequently show Carlsbad twinning. Some plagioclase feldspar can be detected in a few cases, but most of the feldspar appears to be orthoclase.

The quartz occurs in crystals which are up to about three-eighths of an inch in diameter. When the thickness is sufficient the quartz has a dark, translucent appearance, when thin, it is transparent, save for a slight white cloudiness. This cloudiness was found, upon examination with the microscope, to be due to very minute inclusions of various minerals and cavities containing liquid and gas. The crystals less than one-eighth of an inch in diameter are usually transparent and an area of four square inches will often show six or eight crystals that have all or part of the crystal faces developed. Both pyramidal and prismatic faces occur. The angles are usually sharp, but occasionally one is seen that is slightly rounded. The remainder of the quartz crystals are irregular in outline. These two modes of occurrence indicate that there are two generations of quartz, the earlier one having the crystal faces. All the larger crystals of quartz have several cracks in them, as may be seen in figures 1a and 2. Some hematite occurs in these cracks. The quartz and feldspar are very intimately intergrown, and have crystallized at about the same time. Biotite and magnetite are present in small amounts. The biotite is black to brown in color, but is more often greenish brown from the chlorite into which it has altered. The magnetite is nearly always found in the biotite as irregular grains, rarely ever with crystalline faces. The muscovite occurs as small hexagonal books or crystals, rarely larger than one-eighth of an inch in diameter. The grains of fluorite are very rarely large enough to be seen with the naked eye, and are usually associated with the biotite. They are purple in color. The grains of pyrite are often one-sixteenth of an inch in diameter.

The microscope shows that the feldspar is orthoclase in part only. Microcline may exceed the orthoclase in amount and plagioclase may also. But on the whole, the orthoclase is the more abundant and the microcline and plagioclase are nearly equal in amount. The plagioclase varies from oligoclase-andesine to andesine. All the feldspars are kaolinized. Many contain as inclusions, other minerals, such as magnetite and hematite grains, some biotite (now largely chlorite) and fluorite, with very rarely a crystal of apatite. These inclusions are usually more abundant in the plagioclase than in the other feldspars, but this does not always hold.

The quartz is the interesting mineral in the rock because it is the mineral which should contain the fluidal cavities, if the view which holds them to be the cause of the breaking up of the stone is correct.

As a rule the quartz is clear and transparent. Cracks may be seen running in various directions. Occasionally some are seen which are parallel, suggesting that they are along the cleavage lines of the quartz. (Quartz is usually stated as having no cleavage, which is generally correct as far as can be seen in most specimens. It does have an imperfect cleavage parallel to the pyramidal face *r*.)

Running in various directions through the quartz may be seen more or less sinuous lines of inclusions. There is a strong suggestion that these lines are parallel to the crystal faces of the quartz in some crystals. The lines are very small and are not closely spaced. This is evident from the fact that the quartz is transparent to translucent. Not all the inclusions are in lines or rows. Many are scattered through the quartz, often aggregated in clouds, but usually disseminated. These inclusions are very minute. Measurements on a great many gave diameters from .005 mm. to .00027 mm., the average being about .0025. The inclusions consist of grains of fluorite, magnetite, apatite, a greenish colored material which is believed to be a greenish biotite or chlorite, and the fluidal cavities. The cavities, chlorite, and fluorite are the most abundant, and in the order they are mentioned. The chlorite is in irregularly shaped grains, which are usually the largest of the inclusions. They do not show the arrangement into lines that the other inclusions do. The fluorite occurs in shapeless grains and also as small crystals, showing the characteristic square outline. They may have, even in the very small grains, a purplish color like the larger grains, but the majority are colorless. They show a tendency to arrange themselves into lines, as though they had been pushed along by the growing crystal. This is not a marked feature, however.

The fluidal cavities are of particular interest. They are all very minute, the diameters given above applying to them, as well as to the other inclusions. On the whole, however, the cavities are smaller than the largest size given, i. e., 0.005 mm. They are irregular in shape but many are oblong in outline. Sometimes these cavities contain a small bubble of gas or air. This bubble is in motion in about one-third of the cavities, but occasionally nearly every cavity has one, which constantly moves from one part of the cavity to another. They are called "moving bubbles." The diameter of one of the largest seen was estimated to be 0.00009 mm. It was in a cavity 0.0027 mm. in diameter. Some of the cavities probably contain air or gas alone and some liquids alone, but it is not possible to distinguish between them unless they contain a bubble. These fluidal cavities show the same tendency, as does the fluorite, to be arranged in wavy lines or rows, although many are scattered throughout the quartz crystal. The more cloudy quartz crystals contain the inclusions in this disseminated manner. The relative abundance of the fluidal inclusions

is a fact which our problem demands but it was found impossible, however, to make a quantitative determination. Seen megascopically, or even with a binocular magnifying twenty-five times, the inclusions appear very numerous. This appearance is misleading, however, and is due to the reflection of the light from each one, giving to the quartz the cloudy appearance, and so this cannot be relied upon as an indication of the abundance of the cavities. The inclusions make up about one per cent of the quartz. The fluidal cavities comprise about fifty to seventy-five per cent of this one per cent or from one-half to three-fourths of one per cent. This is merely an estimate and may be too low, but is thought to represent the amount fairly well. On the whole, we see that they comprise a very small part, indeed, of the quartz. It might be noted here, that this is the conclusion of other men who have studied the inclusions of rock sections. The minute size of the fluidal cavities, and their rarity, are facts which should be kept in mind.

The other constituents of the granite make up but a small percentage of the rock. Biotite, magnetite, and muscovite are the most important. The biotite is usually more or less altered to chlorite. The biotite shows some pleochroism but is usually green in color and the pleochroism is not marked. Magnetite, some original and some secondary after biotite, is very common in the biotite. It also occurs in the other minerals. The chlorite is in shreds which are usually radiating and it shows the characteristic interference tints. It has replaced the biotite, or at least, partly so. The muscovite shows the usual interference tints and was one of the later minerals to crystallize.

The only common accessory mineral, aside from magnetite, is fluorite. Large grains and crystals of this mineral, usually a deep purple in color, but also colorless, were seen in all the sections made from this granite. Usually it is found near the biotite, but this is not a necessary mode of occurrence. Some of the crystals showed the characteristic square section of fluorite, and showed also the cleavage lines of fluorite. The presence of fluorite as one of the inclusions in quartz has already been noted. It also occurs abundantly as inclusions in the feldspar. It should be noted in this connection that large grains of fluorite were found in the small veins in the granite in Sheahan's Quarry. Some sections were made of the quartz taken from these veins and it was found to contain much fluorite as one of the inclusions. The inclusions were very commonly crystals. Rarely, a small rod of apatite was seen. In two cases a minute garnet was observed. Hematite was seen in various minerals, but usually in cracks in the quartz, and in the feldspars.

A. J. Sheahan Granite Company, Old Quarry.—This quarry was formerly operated by this company and lies a short distance to the west of Graniteville.

The granite is a dark red color, but of a lighter shade than that at their present quarry. The color and texture vary in different parts of the quarry. It consists essentially of orthoclase and quartz with small amounts of biotite, chlorite, magnetite, hematite, muscovite, and fluorite. The estimate of the orthoclase and quartz gave 67 per cent and 33 per cent respectively. The crystals of orthoclase are from about one-fourth inch down, with the exception of the phenocrysts, which may be nearly an inch in diameter and show Carlsbad twinning. A pink plagioclase, in grains the size of the orthoclase, can be recognized. The quartz occurs in crystals three-eighths of an inch or less in diameter. It is more or less transparent to translucent, except for some which has crystalline faces developed, and this has a dark, smoky appearance. All the larger crystals are full of cracks. Some of the orthoclase contains small quartz crystals. The few flakes of biotite are black, save where they are altered to chlorite and magnetite or more rarely to hematite. Magnetite and hematite are very common all through the rock, occurring in small grains. Most of the magnetite was derived from the biotite which seems to have been iron rich but some of it has crystal faces, thus indicating a different origin. Only a few flakes of silvery, white muscovite occur. There is also a grain or two of purple fluorite.

The microscope shows that the rock consists of plagioclase, microcline, orthoclase, and perthite, (in the order named) with quartz and some minor constituents. The feldspar is kaolinized and contains inclusions of chlorite and fluorite. The plagioclase contains most of the fluorite and also appears to have crystallized out before the other feldspars. The quartz contains numerous cracks and inclusions of chlorite, fluorite, and fluidal cavities. The inclusions are arranged in sinuous lines or rows which were observed to cross from one grain to another in some of the crystals. The inclusions are in the quartz which crystallized out last. The fluidal cavities are very minute but numerous, as in the other granite. A great many moving bubbles occur. The biotite, muscovite, and chlorite present the usual characteristics as described above. The magnetite and hematite were derived, in large part, from the biotite. The fluorite occurs as inclusions in the feldspar and quartz.

Schneider Granite Company's Quarry.—Megascopically this granite is a coarse-grained, slightly porphyritic rock of a dark red color. The feldspar crystals are three-eighths of an inch in diameter or less, while the phenocrysts are about three-fourths of an inch in length. Carlsbad twins are common. Both orthoclase and plagioclase can be recognized, the latter usually having a lighter shade of red. Some of the crystals contain chlorite, especially in the interior, and this gives them a greenish color. The estimate of the relative percentage of feldspar and quartz showed 72.5 per cent of feldspar and

27.5 per cent of quartz. The quartz occurs in translucent to transparent crystals three-eighths of an inch or less in diameter. The smaller crystals show some crystal faces which are sometimes pyramidal, and these crystals are usually of a slightly smoky color. All of the larger quartz crystals are badly cracked and shattered, and some of them show a slight cloudiness. Biotite is quite common, but is much altered to chlorite, magnetite, and hematite. The magnetite is in grains one-eighth of an inch across. A few flakes of muscovite occur. Pyrite crystals one-sixteenth of an inch in diameter are very common and are usually associated with the chlorite.

Under the microscope the rock is seen to consist of feldspar, microcline, plagioclase, and orthoclase in order of their abundance. Quartz, with some 3 to 5 per cent of minor minerals, makes up the remainder of the rock. The feldspars are all kaolinized to a certain extent, and also contain numerous inclusions of chlorite and fluorite. The former is in rods and shreds, some .182 mm. in length but most of them about .02 mm. The fluorite is in crystals and grains which are smaller than the chlorite, on the average. The quartz is full of cracks and contains many inclusions of which fluorite in grains as small as .00026 mm. is common. There are a few grains of other minerals, among them a very minute garnet. The fluidal cavities are very abundant and only a few bubbles were recognized. The biotite is largely altered to chlorite and the iron oxides. The latter are so abundant as to suggest that the biotite was iron rich. No large grains of fluorite or muscovite were seen.

Paving-block material from Schneider's Quarry.—No slide was made of this rock as such material is not used in building operations. Megascopically, this rock might be called a granite-porphyry. The ground mass is crystalline and fine-grained but the constituents can be recognized. The phenocrysts rarely exceed five-eighths of an inch, and consist of feldspar, which is often idiomorphic, and of quartz. The feldspar phenocrysts are lighter colored than the feldspar in the ground-mass, which is a dark pink. They show a zonal arrangement, and usually contain considerable chlorite which stains the mineral green. They occasionally contain unaltered biotite. The quartz rarely exceeds three-eighths of an inch as phenocrysts, and averages about one-eighth of an inch. Crystal faces are common, both pyramidal and prismatic faces occurring. Only the larger crystals are cracked, the smaller ones, one-eighth of an inch or less in size, are usually translucent to transparent, with the same tendency to a smoky tint observed in the other rocks. The ground mass contains some small grains. Biotite is much more abundant in this rock than in any of the above. It is scattered throughout the rock in sufficient amount to give it a grayish tinge. Chlorite and the iron oxides are formed when it is altered. A few small grains of pyrite occur.

Missouri Granite Construction Company's Quarry.—This quarry is located three miles southwest of Knoblick, Missouri. The granite is a medium-grained, slightly porphyritic rock, of a light red color, consisting of feldspar, quartz, and biotite, with phenocrysts of orthoclase, and quartz. The feldspar varies in color from pink to red. The quartz is in rounded grains, which usually have a milky, translucent appearance. Cracks are common in it. The biotite is dark green to black. An estimation of the percentage of the constituents is as follows: 5 per cent of the biotite and its alteration products, chlorite and the iron oxides, 69.4 per cent of feldspar, and 25.6 per cent of quartz. This is the lowest percentage of quartz in any of the granites of which an estimate was made.

The microscope shows that the feldspar is orthoclase and plagioclase and that both are strongly kaolinized. The plagioclase is more altered than the orthoclase. It is of interest to note that there is no microcline in this rock and that the plagioclase is a basic variety, probably labradorite. The feldspar contains many inclusions of chloritic and other material. The quartz is very commonly idiomorphic. The angles between the faces are sometimes rounded, but they still possess their six-sided character, which indicates that they crystallized out early in the solidification of the rock. It contains many inclusions which are usually of some mineral, but are so small that the mineral could not be determined. The inclusions are often in rows, parallel to the pyramidal faces of the quartz, indicating that they were pushed along by the growing crystal. When not so arranged they are scattered through the crystal. Many fluidal cavities, containing liquid or gas or both, can be seen. Few bubbles are moving. Some cavities contain minute crystals. The biotite is largely altered to chlorite and magnetite. Many rods of apatite were found in this rock.

Milne and Gordon Quarry.—This quarry is about two miles west of Knoblick, Missouri, and near Syenite postoffice. The rock is a reddish to grayish, medium-grained granite consisting of orthoclase, quartz, and biotite. The feldspar varies in color from pink to red, and the larger crystals show a zonal structure. The quartz is in smaller crystals than the feldspar, but is usually very much shattered. the feldspar is 29 to 71. The biotite makes up only a very small It is transparent to translucent. The ratio between the quartz and percentage of the rock. It is altered to chlorite and magnetite.

Under the microscope the rock is seen to consist mainly of orthoclase and quartz, with a small amount of basic plagioclase and minor minerals. The orthoclase and plagioclase are very much altered to kaolin. The quartz crystallized last as it fills in the space between the feldspar. Mortar structure occurs. The quartz is full of inclusions of cavities, fluorite, mica, and some indeterminate grains. Some of the liquid and gas inclusions are very large and

occasionally are arranged in lines. They contain some very large bubbles. Biotite presents its usual alteration products.

Gilsonite Quarry.—The granite from this quarry is dark gray in color. At a distance it has a bluish cast and is known as the blue granite. It is medium-grained with an occasional phenocryst of white, gray, or reddish feldspar. Scattered through the rock are segregations or "knots" of the dark mineral biotite and sometimes of hornblende. These knots are sometimes an inch or two in length. The rock consists primarily of feldspar, biotite, and some quartz, with magnetite and pyrite, the latter being very abundant.

The microscope shows that the feldspar is largely orthoclase, with some plagioclase, both being altered to kaolin. The orthoclase shows zonal banding. The quartz is in small crystals with part of the faces well developed. It contains a few inclusions of liquid or gaseous cavities and some other material (not determined) arranged roughly in lines. The biotite is abundant and is altered, as usual, to chlorite and magnetite. There is much apatite throughout the slide. There is a small amount of hornblende in the segregations. The other minerals in them are feldspar, biotite, some quartz grains, apatite, and magnetite.

CHAPTER II

PHYSICAL TESTS

A series of tests were made to determine the crushing strength, the effect of heat on the crushing strength, and the amount of expansion when heated.

The compression tests were made with a 150,000 pound Reihle testing machine. The blocks to be tested were approximately two-inch cubes, polished on the two opposite faces, which were as nearly parallel as possible. (See figures 1a, 2, and 4a.) The other four sides were rough. (See fig. 1b.) The blocks were crushed without being bedded in any material. The polished faces were placed on the steel head block of the testing machine, the lower block being rotated in such a manner that the bearing could be brought upon the entire surface of the block, if the faces were not exactly parallel. In most cases only two blocks from each quarry were tested for the compressive strength before heating, and the average of the two was taken.

There was considerable variation in the crushing strength of some of the blocks, which was, in some cases, probably due to defects produced by trimming while they were being made, and in others, because the bearing surface was uneven. The blocks failed with a loud report and the fragments flew in all directions. The cones which were obtained were slender and long; in fact, there was no prominent, central cone, but a number of sharp splinters. (See fig. 3.) After the blocks were heated they failed with less violence and much better cones were obtained. (See figures 8a and b.) The crushing of the various granites is shown in table 1.

Four blocks from each set were tested to determine the effect of heat on the crushing strength. The temperatures were measured with a La Chatelier thermo-couple, which would read to 1600° C. It was found rather difficult to hold the temperature at 500° C. and 750° C. respectively for thirty minutes; in fact, a few degrees, two to four, up or down was as near as could be gotten to the two temperatures mentioned. This variation or even a larger one would have no effect on the results, as the temperatures were not near enough to the inversion temperature of quartz to affect it, even if it were probable that they would. It would not be possible to control the temperature in an actual fire, and our working temperatures were arbitrarily chosen with regard to certain physical properties of the quartz, as will be explained later. The tests were made in a Denver Fire Clay Company gas furnace, number 12. The four blocks were placed in the furnace

TABLE 1. THE CRUSHING STRENGTH OF THE UNHEATED GRANITE.

Quarry and Locality	Number of set	Number of block	Area of crushing surface	Crushing strength	Strength per square inch	Average crushing strength	Remarks
A. J. Sheahan Granite Co., Graniteville, Mo.	I	4	4.00	80,400	20,100	26,030	Explosive break.
	I	5	4.24	123,890	29,220		
	I	6	4.07	116,090	28,530		
	II	3	4.10	107,750	26,280		
A. J. Sheahan's Old Quarry, Graniteville, Mo.	III	6	4.17	113,530	27,225	27,000	Explosive break.
	III	4	3.98	106,600	26,780		
Schneider Granite Co., Graniteville, Mo.	IV	3	4.00	125,170	31,290	31,290	Explosive break. Paving block material.
	V	3	4.12	151,000	36,650	34,960	
	V	7	4.14	138,000	33,330		
Missouri Granite Construction Co., Knoblick, Mo.	VI	8	4.10	133,380	32,530	28,845	Explosive break.
	VI	11	3.95	99,400	25,160		
Milne and Gordon, Syenite, Mo.	VII	2	3.95	102,200	25,900	25,100	Explosive break.
	VII	6	3.95	96,000	24,300		
Gilsonite Granite Co., Knoblick, Mo.	VIII	5	4.10	149,650	36,500	34,875	Explosive break.
	VIII	6	4.00	133,000	33,250		

at the same time, and the temperature was gradually brought to 500° C. where it was held for half an hour. Two of the blocks were then taken out and one was allowed to cool in the air, while the other was cooled in a stream of water. The temperature of the furnace was then raised to 750° C., where it was held for half an hour again. The remaining two blocks were then taken out and cooled in the same way as the others. The polished surfaces of the blocks were studied before and after heating, with the results given in chapter III. There were usually cracks, which could be seen with the naked eye. (See figures 4b, 5a and b, 6 and 7.) When the blocks were heated the feldspar lost some of its red color and the quartz became more or less milky white. (See figures 5b, 6 and 7.) These blocks were then crushed; the difference in crushing strength between them and the unheated specimens is given in table 2. The heated blocks had a much greater crushing strength than it was expected they would have.

The results of these tests are shown by the accompanying curves (fig. 9). The curve includes the strength of the unheated specimens of the same rock, and all the curves show the marked decrease in the strength of the granite. The difference is greater between the unheated specimen and the average of those heated to 500° C., than between those from 500° C. to 750° C. The average strength of all the unheated or fresh granite was 29,260 pounds per square inch and that of the blocks heated to 500° C. was 18,610 pounds, or a difference of 10,650 pounds. The average strength of the blocks heated to 750° C. was 10,990 pounds per square inch, or a difference of 7620 pounds. The total average loss of strength was 18,270 pounds per square inch. Such a loss of strength becomes a serious matter wherever the granite so heated supports a large load. These averages, plotted as a curve, show the decrease at a glance. (See the curve for the average of all the sets, fig. 9.) Two of the sets were heated only to 700° C., but the results differ but by a few pounds from those heated to the higher temperature. The results obtained from the tests of the material from the Milne and Gordon quarry are very unsatisfactory, as the cubes crumbled while yet in the furnace, and there is a very wide difference in the strength of the two specimens heated to 500° C.

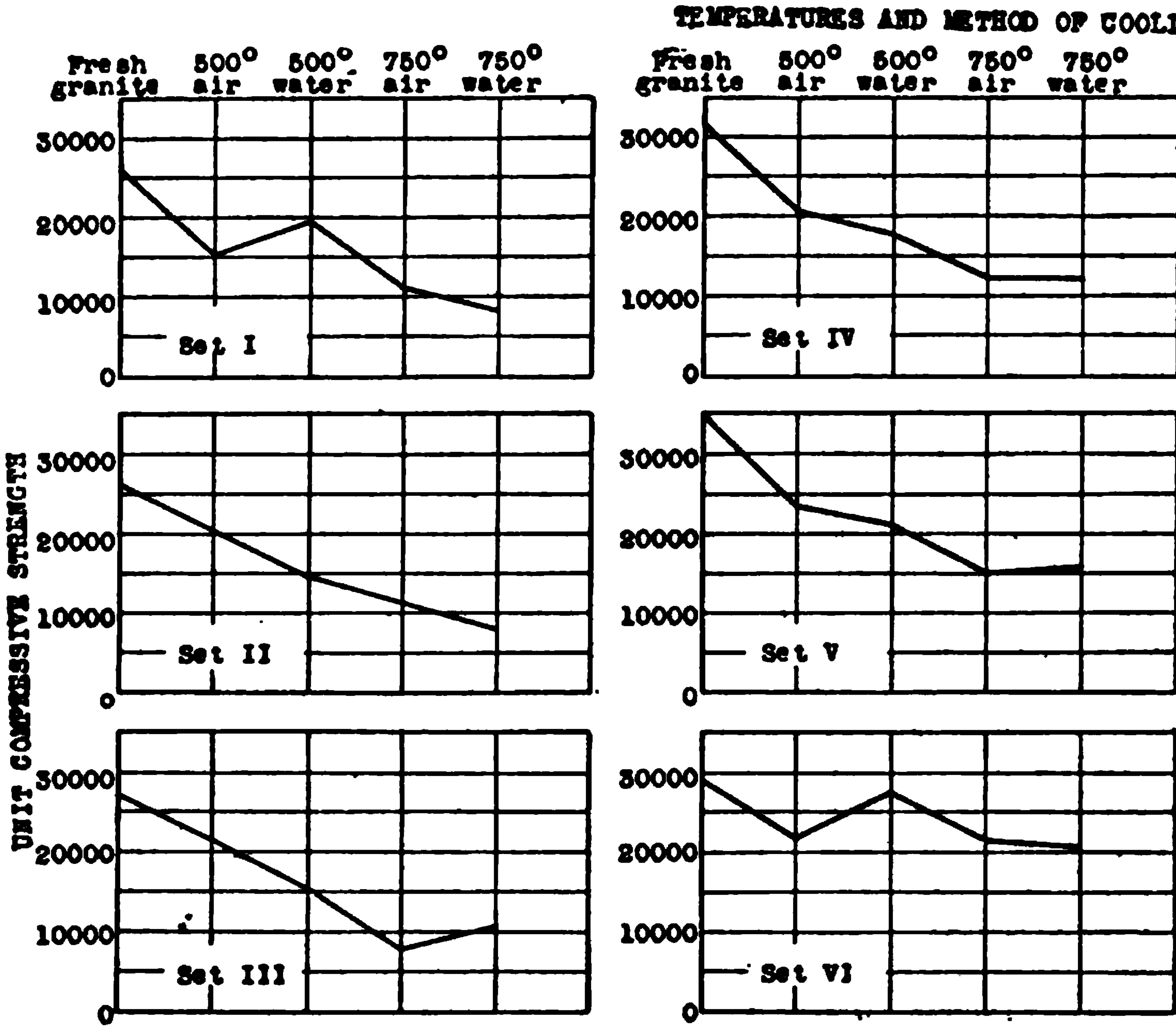
Another interesting feature brought out by the tests is that the sudden cooling by plunging into water is not as damaging to the stone as it has been thought to be. In four of the sets the water-cooled cube showed greater strength than the four cooled in air. One of these was from Graniteville and the others were the three sets obtained from the vicinity of Knoblick. On the whole, the last three were finer-grained than the Graniteville material, but even one of the sets from there showed this variation; hence the cause is not

TABLE 2. CRUSHING STRENGTH AFTER HEATING.

Quarry and Locality.	Number of set	Number of cube	Temp. at which the cube was held for 30 minutes	Cooled in	Area of crushing surface	Total crushing strength	Crushing strength per sq.in.	Remarks
A. J. Sheahan Granite Co., Graniteville, Mo.	I	1	500°C	air	4.0	61,280	15,320	
		11	500°C	water	4.0	78,000	19,500	
		7	750°C	air	4.0	44,000	11,000	
		9	750°C	water	4.1	33,300	8,120	
A. J. Sheahan Granite Co., Graniteville, Mo.	II	1	500°C	air	4.0	81,000	20,240	
		6	500°C	water	4.1	59,610	14,540	
		2	700°C	air	4.0	44,250	11,060	
		5	700°C	water	4.0	32,130	8,030	Only one face polished.
A. J. Sheahan Granite Co., Graniteville, Mo. Old Quarry.	III	3	500°C	air	4.2	90,800	21,640	
		1	500°C	water	4.0	60,560	15,140	
		5	700°C	air	4.0	32,000	8,000	
		7	700°C	water	4.0	42,120	10,530	
Schneider Granite Co., Graniteville, Mo.	IV	4	500°C	air	4.1	84,160	20,500	
		1	500°C	water	4.0	70,810	17,700	
		5	750°C	air	4.1	49,300	12,020	
		2	750°C	water	4.1	49,660	12,110	

TABLE 2. Continued.

Quarry and Locality.	Number of set	Number of cube	Temp. at which the cube was held for 30 minutes	Cooled in	Area of crushing surface	Total crushing strength	Crushing strength per sq.in.	Remarks.
Schneider Granite Co., Graniteville, Mo.	V	1	500°C	air	4.2	95,740	23,280	Paving block material.
		2	500°C	water	4.1	86,040	21,000	
		6	750°C	air	4.1	61,300	15,000	
		8	750°C	water	4.1	64,380	15,700	
Missouri Granite Construction Co., Knoblick, Mo.	VI	1	500°C	air	4.0	86,860	21,715	
		2	500°C	water	4.0	88,480	22,120	
		4	750°C	air	4.1	67,490	16,460	
		3	750°C	water	4.0	62,370	15,590	
Milne and Gordon, Knoblick, Mo.	VII	4	500°C	air	4.0	38,700	9,675	
		5	500°C	water	4.1	66,400	16,200	
		1	750°C	air	----	------	-----	Fell to pieces in the furnace.
		3	750°C	water	----	------	-----	
Gilsonite Granite Co., Knoblick, Mo.	VIII	1	500°C	air	4.1	94,580	23,070	
		2	500°C	water	4.1	107,140	26,130	
		3	750°C	air	4.1	73,610	17,980	
		4	750°C	water	4.0	57,020	14,255	



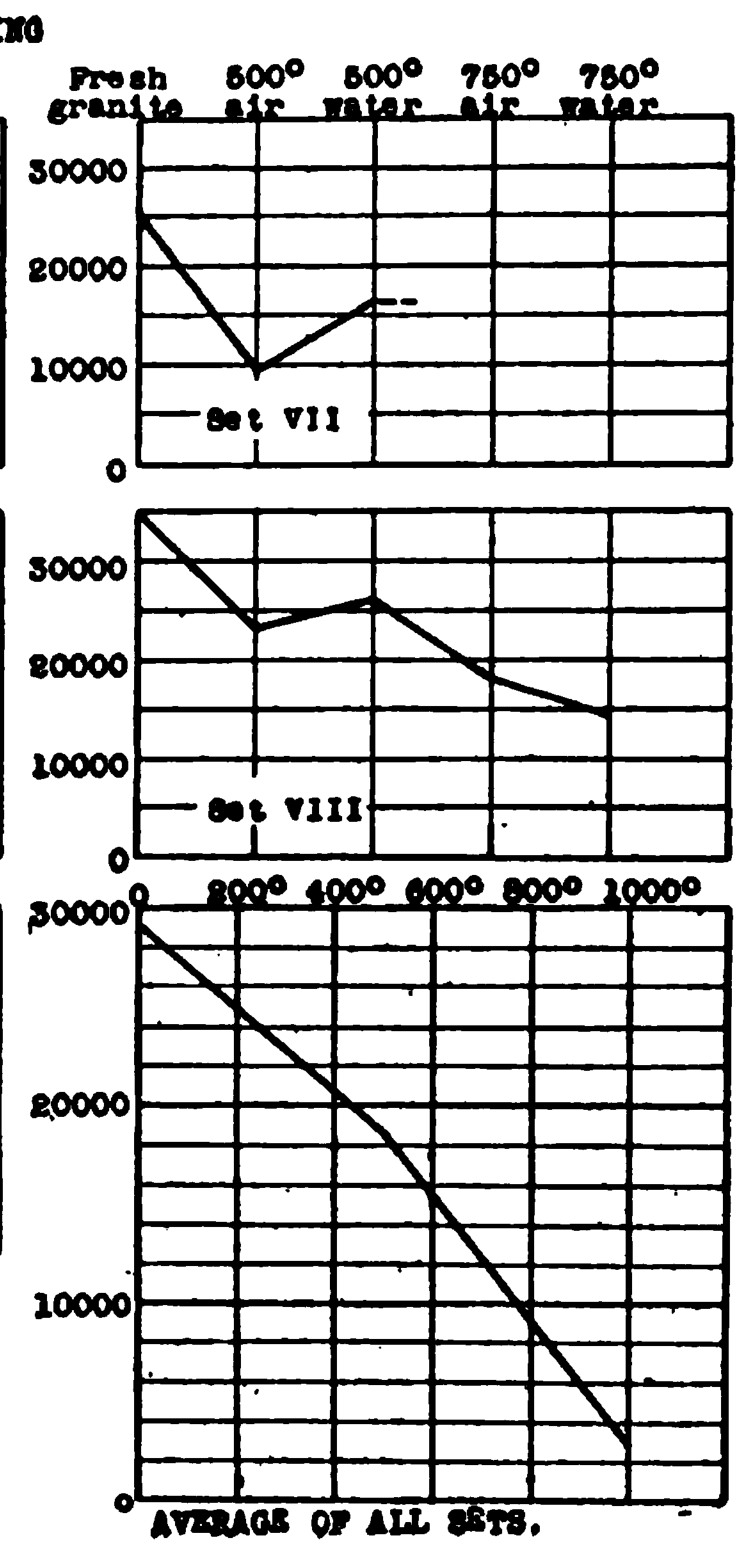


Fig. 9. Curves showing the strength of the granite at the temperatures used. For completeness, the average curve includes the rocks heated to 1000°C. It shows that the decrease in strength is approximately uniform.
Compressive strength in pounds per square inch. Temperatures in Centigrade degrees.

wholly the difference in texture. The mineralogical composition probably plays a part, and defects in the cubes may also be an explanation. The average excess strength of those which are stronger after cooling in air is 4320 pounds, while the excess for those cooled in water is 3540 pounds, so the difference is very little. The strength of those specimens heated to 750° C. and cooled in air is on the average about 1000 pounds higher than when they were cooled in water, though slightly favoring the slower air-cooling. Remembering that we are dealing with only eight sets, a tentative conclusion would be that the water bath is not as damaging as it has usually been thought to be.

Tests were made on a series of blocks to determine at what temperature the heat caused the block to lose its strength. The following tables show these results (tables 3 and 4). The first series consisted of unpolished blocks, from Sheahan's Quarry at Graniteville, which had to be imbedded in plaster of paris for crushing. These blocks were very weak, for the unheated blocks that were crushed were only half as strong as the unheated, polished blocks, and there was greater fluctuation of the crushing strength. The difference was no doubt due to the fact that the blocks were injured

TABLE 3. CRUSHING STRENGTH OF A SERIES OF POLISHED BLOCKS HEATED TO VARIOUS TEMPERATURES. COOLED IN AIR. THE MATERIAL WAS FROM THE MISSOURI GRANITE CONSTRUCTION CO., KNOBLICK, MO.

Number	Temperature for 30 min.	Area of crushing surface.	Crushing strength (total)	Crushing strength per sq. in.
1	250°C	4.0	116,210	29,050
2	300°C	4.0	87,000	21,750
3	350°C	4.0	93,420	23,355
4	400°C	4.1	93,971	22,920
5	450°C	4.05	79,600	19,900
6	500°C	4.00	86,860	21,700
7	750°C	4.1	67,490	16,460
8	800°C	4.0	34,660	8,665
9	850°C	4.0	45,600	11,400
10	900°C	4.1	27,120	6,600
11	1000°C	4.0	16,040	4,010

in roughing them out and this was increased by the imbedding. The temperatures used were from 250° C. to 1000° C., starting at 250° C. and increasing from 25° C. to 50° C. at a time. The blocks were left in the furnace thirty minutes at the desired temperature and were cooled in air. A shortage of polished blocks caused some of the intermediate temperatures to be left out. However, the results are not affected by this. Curves showing the various strengths are shown in figure 10.

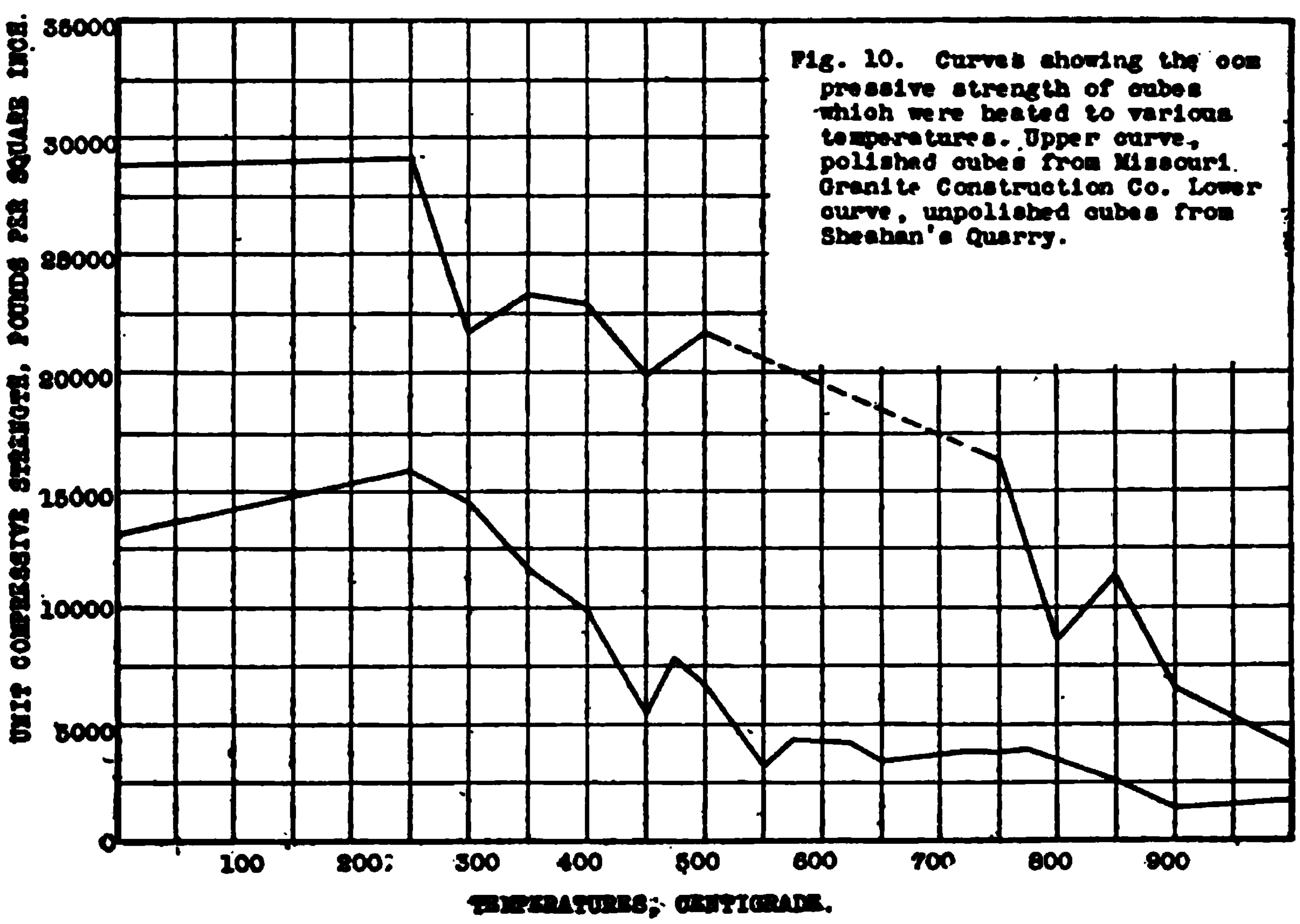


Fig. 10. Curves showing the compressive strength of cubes which were heated to various temperatures. Upper curve, polished cubes from Missouri Granite Construction Co. Lower curve, unpolished cubes from Sheahan's Quarry.

It is to be noticed that the strength of the granite declines rapidly from the very first. The loss between 250° C. and 500° C. in the series from the Missouri Granite Construction Company at Knoblick, Missouri (Table 3) is 7350 pounds, and for the unpolished series from Sheahan's Quarry, Graniteville, Missouri, the loss is 9140 pounds. Unfortunately, the total loss of the granite cannot be obtained from these data because of the undoubtedly erroneous values of the strength of the unheated specimen. However, the same information is given in the sets of blocks, and for the Sheahan's Present Quarry the loss on heating to 500° and cooling in air is 8250 pounds, while for the Missouri Granite Construction Company the loss was 7130 pounds. Comparing these figures, and remembering that they are based on the tests of a few blocks, we see that the granite is not greatly affected at 250° C. The decline in strength is almost linear and rather

TABLE 4. THE CRUSHING STRENGTH OF A SERIES OF UNPOLISHED BLOCKS OF GRANITE HEATED TO VARIOUS TEMPERATURES. COOLED IN AIR. MATERIAL FROM SHEAHAN'S QUARRY, GRANITEVILLE.

Number	Temperature for 30 minutes	Area of crushing surface	Crushing strength (Total)	Crushing strength per sq. in.	Remarks.
1	20°C	4.0	52,320	13,080	Average of two blocks.
2	250°C	4.0	63,560	15,890	No change.
3	300°C	4.0	58,140	14,530	Slightly bleached.
4	350°C	4.0	46,840	11,710	Slightly bleached.
5	400°C	4.0	39,830	9,960	Slightly bleached.
6	450°C	4.0	21,930	5,480	Cracks in feldspar and quartz. Quartz whitened. The
7	475°C	4.0	31,000	7,780	Cracks in feldspar and quartz. remainder of the series
8	500°C	4.0	26,990	6,750	Small crack across the face. ring on scratching.
9	550°C	4.0	12,070	3,020	Number of small cracks.
10	575°C	4.0	17,400	4,350	Number of small cracks.
11	625°C	4.0	16,950	4,240	Cracks readily visible to eye.
12	650°C	4.0	13,960	3,490	Cracks larger. Light pink.
13	725°C	4.0	15,750	3,940	Cracks large. Pink.
14	750°C	4.0	15,330	3,830	Many small cracks.
15	775°C	4.0	15,960	3,990	Several large cracks.
16	850°C	4.0	10,250	2,560	Several large cracks.
17	900°C	4.0	5,960	1,490	Cracks large and numerous. Much shattered.
18	1000°C	4.0	6,700	1,670	Shattered. Ferromagnesian minerals fused to a slag and the feldspar fused to small drops of glass.

rapid to 500° C. or 600° C. but from this point to about 800° C. the rock is rendered worthless, retaining only ten to fifteen per cent of its crushing strenth.

While there does not appear to be a definite point at which the strength suddenly fails, a rock heated to 500° C. or 600° C. loses the greater part of its strength and is unfit to bear a very large load. At 1000° C. the rock is completely destroyed and can be crumbled in the fingers.

Tests were made for the expansion, at 500° C. and at 750° C., on blocks approximately seven and one-half inches long and two inches square. Three blocks were measured and then placed in the furnace and the temperature gradually brought to 500° C., where it was held for thirty minutes. They were then taken out and measured and allowed to cool in the air. The other three blocks were treated in a like manner except the temperature was 750° C. The table given later shows the results (table 5). The average permanent expansion per inch as shown by the table is .00483 for the temperature of 500° C. or .000,966 for one degree, and .01299 for the temperature of 750° C., or .000,017,3 for one degree. These values are about the same as those of previous determinations.

Four paving blocks, which were about five by seven by twelve inches, were tested to find the effect of heat on larger blocks. Two of these blocks were brought to 500° where they were held for thirty minutes. One of the blocks was allowed to cool in air, the other was cooled in water. The other two blocks were subjected to the same treatment at a temperature of 750° C. Cracks which ran in all directions were developed in these blocks. Those which had been heated to 750° were fractured more than those at 500°. A fairly large piece split off the block which had been heated to 750° and cooled in water.

CHAPTER III

THE EFFECTS OF HEATING ON THE GRANITES

Before the crushing strength of the heated cubes of granite was determined, each one was carefully examined and the effect of the heat and the subsequent treatment noted. These observations thus indicate in a general way what the resulting effect would be if the granite were exposed to the heat of a conflagration, which McCourt regards as being about 843° C. or 1550° F. The temperatures in some fires no doubt go higher than this.

After a careful study had been made of the blocks, they were crushed and slides were made of some of the sets to determine what effect, if any, the heat had had upon the inclusions in the quartz, especially the liquid and gaseous inclusions. As far as the writer is aware this is the first time slides of the rock tested have been made before and after heating, and the results are of interest in throwing light upon the oft repeated statement that the liquid and gaseous contents of the cavities are a probable factor in the disruption of the granite.

EXAMINATION OF THE HEATED CUBES, MEGASCOPICALLY AND WITH A BINOCULAR MICROSCOPE

The polished faces of the cubes lend themselves, especially, to the study of heat effects, as they show the cracks beautifully. All observations made were made upon these faces. It was found that a Leitz Binocular microscope with magnifications of from twenty to fifty-five times was a very valuable aid in the study. It enabled one to see the cracks in their true relationship to the inclusions, and other physical properties of the minerals.

Set I. Sheahan's Present Quarry.

Number 1, 500° C., air-cooled.

The original dark red color of the granite was bleached to a pink during the heating. Many small cracks were developed, the largest being .05 mm. in diameter, while a given crack is usually largest near the edge of the cube. (See fig. 4b.) There are usually only one or two large cracks on the side of a cube and these are near the center, and run more or less parallel to the sides. The cracks usually pass around the quartz grains which are less than 1.5 mm. in diameter, but cross all larger quartzes and also the other minerals. They follow the cleavage and twinning planes of the feldspar, and as the plane of

contact of two minerals is a plane of weakness, a crack usually develops there also. These last mentioned cracks are especially noticeable at the contact where a thin fragment of a quartz grain lies upon the surface of the cube.

The larger grains of quartz became a more or less milky white in color. The smaller ones remained clear and transparent. This change of color is due to the development of numerous cracks which are roughly parallel, or make a slight angle, with the surface of the cube. The binocular showed that the numerous cracks were developed without regard to the lines of inclusions in the quartz. The cracks may parallel a line of inclusions for a short distance, then turn and cross it. It is rather surprising that so few follow the lines of inclusions, for theoretically, these should be lines of weakness and thus should be followed for this, if for no other reason. No cracks could be observed which passed from the lines of inclusions to the surface of the quartz. A comparative study of the quartz in the fresh and heated granite showed that the lines of inclusions were the same in both.

The cracks in the feldspar followed the cleavage or the twinning planes. They are especially noticeable when these planes are at an angle of forty-five degrees or less to the surface. Often the crack along a cleavage plane intersects another crack, and then the fragment of the mineral drops out entirely. The biotite usually expands quite markedly and so projects a little above the surface.

That the stone as a whole is rendered more porous as the result of heating is shown by the peculiar, ringing sound emitted by it on being scratched. Buckley has compared this sound to that observed on scratching a brick. The sound is due to the state of tension which the mineral particles are in, because of the permanent expansion from the heating. Each one acts like the string of a musical instrument, picking up the vibrations produced by the scratching and intensifying it, aided by the increase in pore space from the development of cracks.

Number 11, 500° C., water-cooled.

The color was about the same as that of No. 1, but the more prominent cracks appeared to be larger and slightly more numerous. (See fig. 5a.) The most marked difference was in the cracks in the quartz which were very numerous but were, for the most part, perpendicular to the polished surface. This distribution of the cracks is to be noticed, for in the specimen cooled in air the cracks were not prominent unless more or less parallel to the surface. Not only were these perpendicular cracks found in the quartz, but also in the feldspar to a certain extent. They did not have any recognizable relation to the lines of inclusions in the quartz, and were largely unaffected

a

b

Fig. 1. Sheahan's Quarry.
a. Polished face of granite cube.
b. Rough face of granite cube.
About 1.5 times actual size.

Fig. 2. Fresh granite. Sheahan's Quarry.
Note the numerous cracks in the quartz.
About twice natural size.

Fig. 3. Shape of fragments after crushing unheated cones.

a

b

Fig. 4. Granite from Sheahan's Quarry.
a. Unheated.
b. Heated to 500°C. air cooled.

a

b

Fig. 5. Granite from Sheahan's Quarry.
a. Heated to 500°C. water cooled.
b. Heated to 750°C. water cooled.

The quartz in b is white, due to the shattering by the water. Note the small holes where fragments have dropped out.

Fig. 6. Heated to 700°C. air cooled.
Sheahan's Quarry.
About 1.5 times actual size.

Fig. 7. Heated to 750°C. water cooled.
Sheahan's Quarry.
Note the white color of the quartz in this figure. Compare with Fig. 6, which was air cooled.
Enlarged nearly twice.

a

b

Fig. 8. Shape of fragments after crushing heated cubes. Slightly enlarged.
a. Heated to 500°C. air cooled.
b. Heated to 750°C. air cooled.

TABLE 5. EXPANSION OF GRANITE. MATERIAL FROM SHEAHAN'S QUARRY, GRANITEVILLE, MISSOURI.

Number	Temperature Centigrade.	Length before heating. inches.	Length while hot inches.	Length when cooled. inches.	Expansion while hot. inches.	Permanent expansion. inches.	Average permanent expansion. in. for 500°C	Average permanent expansion for one degree in inches.
1	500°	7.6719	7.7188	7.7031	0.0469	0.0312		
2	500°	7.6250	7.6875	7.6719	0.0625	0.0469	0.00483	0.000966
3	500°	7.5625	7.6250	7.5938	0.0625	0.0313		
4	750°	7.6562	7.7812	7.7656	0.1250	0.1094		
5	750°	7.5938	7.7188	7.6875	0.1250	0.0937	0.01299	0.0000173
6	750°	7.5938	7.7188	7.6875	0.1250	0.0937		

by the cleavage planes in the feldspar. These cracks appear to owe their origin to the strains set up in the surface by the rapid cooling in water, for they do not extend very deep, only about one millimeter in the specimens heated to the higher temperature.

The biotite was bleached to a brown color. The twinning lines of the plagioclase are often seen in the heated specimen, and are probably due to the accentuation given them by the heating. The surface has a peculiar shagreened appearance and the cube emits the ringing sound when scratched.

Number 7, 750° C., air-cooled.

The rock was bleached to a lighter pink than either of the cubes heated to 500° C. The surface was roughened by the unequal expansion of the various minerals, and the rock is more friable than the others. The cracks were larger and more numerous than in the other cubes, likewise, the smaller cracks appear more numerous in the quartz than in the feldspar. They are about one millimeter long and one-fourth millimeter in diameter, thus having the appearance of slender rods.

As to the relationship of the cracks to the inclusions in the quartz nothing could be seen. They were in quartz grains which were perfectly free from inclusions, as well as in those which contained the inclusions scattered through the grain, rather than in rows. Often they were more numerous around the borders of the larger crystals than in the inclusion-filled, central parts. Many small quartz grains were free from cracks.

Number 9, 750° C., water-cooled.

The surface of the specimen was roughened, and the cracks developed were about the same as the last specimen described. (See fig. 7.) When scratched it emitted a marked ring which sounded as though the minerals were loosely held together. Further evidence of this friable character is found in the numerous small chips that come off the sides by handling. The color is the same as in No. 7.

Nearly every grain of quartz is white because of the innumerable small cracks which fill it. (See fig. 7.) It is completely shattered, the cracks being about roughly perpendicular and about a millimeter in depth. The resulting particles were about .05 mm. in diameter. The shattering was caused by the sudden immersion of the quartz in water. The cleavage lines of the feldspar are more prominent than they were in the previous specimens. The color of the biotite was changed to a golden brown, and the crystals were permanently expanded so that they projected above the surface of the cube.

Set II. Sheahan's Present Quarry.

Number 1, 500° C., air-cooled.

The original dark red color was bleached to a pink. Two rather large, prominent cracks were developed on each face, one being larger than the other. Many cracks were developed around the minerals of the rock. The surface was slightly roughened from their permanent expansion, especially from that of the feldspar crystals.

The quartz was slightly whitened from the incipient cracks which were developed in it. They are found in the crystals that are free from inclusions as well as in those filled with them, showing that the inclusions are not essential to their formation. The cracks resemble those developed in the specimens heated to 750° C., and are mostly perpendicular to the surface. The feldspar has cracks along the cleavage and twinning planes, as usual.

Number 6, 500° C., water-cooled.

The color and roughened surface are about the same as in No. 1. There was a large crack on the face which rested upon the bottom of the muffle in the furnace and a smaller one on the top face. These run roughly parallel to the sides of the cube. The cracks around the grains are smaller and more numerous than in number one. This is due to the sudden cooling.

The cracks in the larger quartz crystals, which are of a marked whitish color are very abundant and produce a series of polygonal rods of more than a millimeter in length. The small, thin grains of quartz, less than .5 mm. in diameter, which lie on the surface have pulled away, developing a crack behind them. The cracks are present, irrespective of any inclusions and do not appear to be in any way connected with them. The feldspar has the usual fractures along the cleavage planes.

Number 2, 700° C., air-cooled.

The color of this specimen did not become paler at the higher temperature as in the first set. (See fig. 6. Compare with fig. 7.) The surface was very much roughened and had the appearance of being shattered, the cracks bearing this out, for they were larger than in the other specimens of this set but no more numerous. Four fairly large cracks developed on the base and only one small one on the upper surface. This was due, no doubt, to the floor of the muffle being hotter. The cracks around the grains were no more numerous but were larger than in those at the lower temperatures.

The quartz contains the usual inclusions in clouds and lines, but those crystals which were free from inclusions were as full of cracks as those with them. They were perpendicular to the surface and formed small parallel, polygonal rods. The feldspar was much shattered in the same manner as in the other cubes.

Number 5, 700° C., water-cooled.

The color and surface were the same as the other specimen heated to 700° C. There were several prominent cracks on the base and some small ones on the top, and there were many small cracks around the grains.

The quartz was completely shattered and its color was white. The cracks were perpendicular to the surface and the result was a series of polygonal rods. Cracks in the feldspar followed the cleavage planes, but it was no more shattered than in the specimens heated to 500° C. The cracks in the quartz show no relationship to the inclusions.

Set III. Sheahan's Old Quarry.

Number 3, 500° C., air-cooled.

This rock was coarse-grained, slightly porphyritic and of a dark red color. It was bleached to a pale, pinkish red. It appears to have been the least affected of any of the sets. There are no large cracks, and only one small one on each face. There are many small ones around the crystals. The surface is not roughened to any extent. The quartz, on the whole, is clear and transparent and is not greatly affected with cracks, probably because of the smaller average size of the quartz grains in this rock. They are more or less incipient cracks, nearly perpendicular to the surface and resemble lines of inclusions, in fact, some may be along such lines. The feldspar was affected as in all the other specimens. There does not appear to be much difference in the effect of heat on the feldspar. It cracks along lines of weakness at either of the temperatures used.

Number 1, 500° C., water-cooled.

This granite was bleached as was number 3, but it does not show any large cracks. The usual cracks at the contacts of the minerals are larger than in number three, probably because of the cooling in water.

The quartz in small grains, those less than 1 mm. in diameter, is very clear, with only an occasional incipient crack. The larger crystals are very much shattered. Evidence which shows that the cracks are

not related to the inclusions was found in this specimen. The cracks were very numerous and were parallel. In a basal section of quartz they were parallel and inclined, suggesting that they were produced along the cleavage lines of the quartz. The quartz which showed this was clear and transparent, indicating the absence of inclusions. Cracks were just as abundant in the clear quartz as in that with inclusions.

Number 5, 700° C., air-cooled.

The color produced by the heating was a pinkish red. A few medium-sized cracks developed on the surface, while there were a great many around the minerals, especially the larger ones.

Many incipient cracks were developed in the quartz, parallel to each other even in the smaller crystals. They were often inclined, but were also perpendicular to the surface. Occasionally these cracks are at an agle of 120° to each other, which is significant, in view of their being along the cleavage lines of the quartz. Other quartz grains show the numerous small rods, developed by the cracks being perpendicular to the surface. Some of the small, transparent crystals show incipient cracks. The feldspar is cracked as usual.

Number 2, 700° C., water-cooled.

The color produced was a reddish pink, and the surface was rough from the varying expansion of the crystals. Some large prominent cracks pass through the cube, passing around or cutting through the crystals.

The quartz was completely shattered, and consisted of a mass of small rods, as in the other specimens heated to this temperature and cooled in water. The rods are from .1 mm. down, usually less than .05 mm. The feldspar was affected as usual.

Set IV. Schneider's Quarry.

The fresh, unheated specimen was a coarse-grained, dark red rock. Incipient cracks appeared at the contact of the various minerals, while the quartz was very much shattered, especially the larger pieces. The feldspar, also, contained some cracks.

Number 4, 500° C., air-cooled.

The rock was bleached to a dark pink. Some small, rather prominent cracks developed on the polished face, otherwise the cracks are hardly more numerous than they are in the fresh rock. The cracks at the contact of the minerals are larger, and the slight movement from the expansion at these places has fractured the minerals so that they appear white from the reflected light from each small particle. Much of the quartz is greatly shattered, but this was the case in the

fresh specimen. The inclusions are abundant in some crystals. The feldspar, also, was cracked.

Number 1, 500° C., water-cooled.

The color was the same as in No. 4, but the cracks were larger and more numerous than in the air-cooled specimen. Tne quartz was badly shattered, largely by cracks which are perpendicular to the surface and which produce polygonal rods. This is especially true of the thin fragments of quartz lying upon the surface. The cracks in the quartz are not related to the inclusions. The feldspar is cracked as usual.

Number 5, 750° C., air-cooled.

The rock was bleached to a pale pink. It contains many large, prominent, and quite numerous cracks. The specimen emits the characteristic sound when scratched, and the surface is slightly roughened from the unequal expansion of the various minerals. The cracks in the quartz are perpendicular to the surface and are very numerous. Many cracks were observed which crossed the lines of inclusions and possibly some are along these lines although this cannot be affirmed. The feldspar is cracked as it is in the other specimens.

Number 2, 750° C., water-cooled.

As in all the specimens heated to the higher temperatures, the quartz was completely shattered. It was composed of small rods arranged perpendicular to the face. The feldspar was expanded and split along the cleavage planes. There are some large cracks which cross each other at about right angles, while the surface is rough. Several fragments, small and thin, spalled off the sides.

Set V. Paving-block Material from Schneider's Quarry.

This material was fine-grained and porphyritic. It was brownish red to pinkish red in color. The largest phenocrysts of feldspar were not over one and half centimeters in length, while the largest crystals of quartz did not exceed one centimeter in length.

Number 1, 500° C., air-cooled.

This specimen was bleached to a pink red. There were three prominent cracks on one face and one on the other. The fine-grained ground-mass appears to be full of cracks, largely along the contract of the minerals. Some of the quartz has a milky color, apparently due to inclusions. Nearly all the crystals of quartz are cracked, some with incipient cracks only. They appear in those with inclusions and in

those that are clear. Many are parallel and often inclined to the surface, probably along the cleavage lines of the quartz. The feldspar has many cracks.

Number 2, 500° C., air-cooled.

The color is the same as in No. 1, and the surface is roughened from the permanent expansion of the minerals. One very large crack goes through the center of the cube and there are also several prominent ones, all of which pass straight through every mineral. The large quartz phenocrysts are shattered and even the smaller crystals have a great many cracks. Most of the cracks are perpendicular to the surface, while occasionally they are parallel and inclined. Only a few of the quartz grains contain inclusions and all are shattered, even the small ones with perfect faces.

Number 6, 750° C., air-cooled.

This specimen was bleached by the heat to a lighter shade of pink than was No. 2. The surface was roughened and shows one or two rather marked cracks and several small, minor ones. It emits a ring on being scratched. Some of the larger quartz crystals contain inclusions, but all are shattered, the larger ones especially so. The cracks in the feldspar are along the cleavage planes.

Number 8, 750° C., water-cooled.

The color is the same as that of No. 6, and the surface was roughened. There are a few fairly prominent cracks which are usually in the center. All the quartz is completely shattered by the usual, perpendicular cracks. Some appear to be parallel to cleavage cracks. The feldspar is badly cracked also.

Set VI. Missouri Granite Construction Company.

Number 1, 500° C., air-cooled.

The color of this specimen after heating is a light pink. A few cracks developed along the edges of the cubes but they are not large. Some occur around the minerals. The most prominent are those along the cleavage planes of the feldspars. There are many cracks in the quartz and many beginning to develop. They run in all directions and some of the cloudiness of the quartz may be due to the incipient cracks.

Number 2, 500° C., water-cooled.

The color produced is the same as in No. 1, but the cracks are larger, extending nearly across the cube. The surface is roughened considerably. All the quartz is very much shattered by perpendicular cracks, and many incipient cracks add to the milky white color caused by the inclusions. The former are not related to the inclusions, but the latter may be.

Number 4, 750° C., air-cooled.

The color produced is the same as that of No. 2, but the surface is rougher. There are two large cracks which pass partly through the specimen on one face, and there are several small ones on the other face. The cracks in the quartz are slightly more numerous than in specimen number 2, but are of the same general character. There is no evident connection with lines of inclusions. The biotite is a deep brown.

Number 3, 750° C., water-cooled.

The color and surface are the same as those of No. 4. The cracks in the interior of the face are better developed. There are no large cracks. The quartz and feldspar are full of cracks, as usual. The former is greatly shattered and cracks are no more numerous in those with inclusions than in those without.

Set VII. Milne and Gordon Quarry, Syenite, Missouri.

Number 4, 500° C., air-cooled.

The color caused by the heating is a pale grayish pink, grayish because of the biotite it contains. Only one polished surface shows any cracks, and but three of these were very prominent. This same face had many small cracks well developed, but there were only a few incipient ones on the other face. The quartz shows a great many inclusions scattered throughout the crystal but not arranged in lines. The cracks in it are numerous and perpendicular, but some may be parallel to the surface. The feldspar is cracked along the cleavage planes.

Number 5, 500° C., water-cooled.

The color of this specimen was the same as that of No. 4, with several prominent cracks in the middle of the face. There are numerous small cracks around the grains and they are more abundant in the bottom face, that is, the one that rested on the bottom of the muffle. The quartz does not appear to be more cracked than in the air-cooled specimen. The specimen appears firm, and emits a ringing sound when scratched.

Numbers 1 and 3, 750° C.

These speciments fell to pieces in the muffle when they were touched with the tongs to remove them. The fragments were about an inch square and one was curved so that one edge was one-fourth of an inch higher than the other. The quartz was full of cracks. The

probable cause of the disruption of the specimens was the expansion of the biotite books or crystals, which were very numerous in the rock. They were greatly expanded.

Set VIII. Gilsonite Quarry, Knoblick, Missouri.

Number 1, 500° C., air-cooled.

The original color of this granite was gray but it was bleached to a pinkish gray. There was one large crack and one or two small ones. The quartz grains are small and all are more or less cloudy, although only the larger ones are cracked. Incipient cracks appear at the contact of the minerals. There are cracks in the feldspar. The quartz and feldspar are cracked especially around the numerous basic inclusions, where these have well defined borders.

Number 3, 750° C., air-cooled.

The color produced in this specimen is the same as that of No. 1. A very large crack runs through the center, and there are also a few small ones; otherwise the specimen is the same as No. 1.

Number 3, 750° C., air-cooled.

The color is a lighter, pinkish gray than that of No. 2. One fairly large crack was developed on each face. The binocular showed many small cracks which appear to be at the surface. The quartz is much shattered but the cloudiness of the inclusions is still preserved.

Number 4, 750° C., water-cooled.

The color produced in this specimen is the same as that of No. 3, all the feldspar having a pink color. There was a slight roughening of the surface. One very large crack runs through the cube. The large quartz crystals were completely shattered, but the smaller ones being already very small do not show the water-effects. The quartz is clear save for cracks and inclusions. The chloritic green of the feldspar was changed to a yellowish brown color.

SUMMARY

The study of the heated specimens shows that the granites from each locality are more or less affected by the high temperatures. The material from one of the quarries is not on the market at the present time, but it was included in the series tested, because of its fine-grained texture and slightly different mineral composition; thus giving the results a wider application.

The original color in all the granites was changed to a lighter shade by the heating. The feldspar became a lighter pink and the

quartz usually a milky white, while the biotite changed from black to golden brown.

The rock became more porous as is shown by the sound emitted on scratching the specimen, by the roughened surface due to permanent expansion of the different minerals, and by the cracks. All the specimens were cracked to a certain extent. The size and continuity of the cracks vary with the texture of the rock, being much less well defined in the coarse-grained ones. Also the higher temperature of the bottom of the muffle often caused more cracks to develop there than on the top. In the coarse-grained granites the stresses produced by the heat found relief by developing cracks around the larger crystals of rock. Such cracks are very common in all the rocks of this texture. The larger cracks usually pass through all minerals alike, unless the crystals of the minerals are small. They follow the cleavage and twinning planes of those minerals that have them, but go straight across those that do not have these planes of weakness well developed. Since feldspar has two good cleavage directions and is very often twinned it is full of cracks of all sizes. The cleavage planes make all kinds of angles with the surface and when these are small and intersect cracks fragments of the mineral fall out on handling them.

The quartz is the most interesting of the minerals, for it contains the inclusions which are supposed to aid in disrupting the rock. The study shows that there is no connection between the inclusions and the cracks which cross the quartz. The mere presence of a series of inclusions in a line, whatever they were, would make the plane that contained the line a plane of weakness, and one which a crack produced by relief of stresses in a strained mineral would be likely to follow. As far as can be seen by using the binocular microscope this has probably been the case in some instances, yet the great majority of the cracks are not related in any way to the inclusions of the quartz. They may cross them or be parallel to them in any position.

On the whole, the temperatures used are detrimental to the granite. The strength is decreased in all of the granites, and very decidedly so in some of them. The rock is made more porous, which renders it especially liable to attack by air and water.

RESULTS OF MICROSCOPIC STUDY OF THE HEATED GRANITE

Slides of the heated rocks were made for microscopic study, as was stated above. The study was especially valuable in showing the changes which were produced in the internal structure of the component minerals of the rock. The results cannot be tabulated, hence a brief description of the slides by sets will be given. Much repetition

will be saved by stating certain facts which were common to all the slides.

As the material from which the slides were made was very friable, in making the thin sections of the rock required for microscopic work, the minerals were pulled apart along the more prominent lines of weakness, especially along the cracks developed in the heating. However, for the most part, the separated pieces preserve their positions relative to each other, so that no difficulty was found in studying the character of the line of separation.

The composition of the rocks is, of course, the same as that of the original specimens, so the description given above applies to the slide of the heated rock as well. The feldspars which were very much altered to kaolin are much darker in all the slides of the heated rock. The feldspar shows a slight widening along the cleavage planes, due to the expansion. The biotite, especially the brown colored variety, usually became darker. The iron oxides were not changed save for the development of a little more hematite than the original rock contained. The other minerals, with the exception of the quartz, are very few and are not noticeably changed. The quartz was very carefully studied, of course, and will be fully described in the following pages.

The study includes the size, kind, and arrangement (whether in lines or disseminated) of the inclusions, the size and continuity of any cracks which are in the quartz and their relationship, if any to the inclusions.

Material from Sheahan's Quarry, Graniteville, Missouri

500° C., air-cooled.

The smaller grains of quartz (those under one millimeter in diameter) are often completely shattered, the cracks producing roughly polygonal areas, usually less than .026 mm. in diameter. Rarely, there are some lines of inclusions in these smaller crystals. The larger ones, with many inclusions, are only slightly shattered. In some of the crystals there are numerous, parallel, incipient cracks that are inclined to the surface. These were very frequently noted in many of the slides and are believed to be cracks just beginning to develop along the cleavage planes of the quartz. They may or may not be near or cut across a cavity containing liquid or gas. When they do cut such a cavity there is no change in it. The inclusions consist largely of cavities which contain some liquid and gas, and small grains of fluorite and other minerals. Just what the material in the cavities is, is not known, but it is probably largely water or water vapor and in small part, carbon dioxide which is quite common in such cavities.

It is an interesting fact that not a single moving bubble could be identified in any of the slides of the heated rocks. On the other hand, the cavities are more prominent and easily recognized in the heated specimen than in the unheated rock. They are darker and the borders of the inclusions are broader, in fact, they appear to be gaseous rather than liquid. Occasionally the inclusions are in well defined lines, more or less wavy, but the cracks which are developed, cross them at various angles or run parallel to them. There is no apparent connection between the two.

500° C., water-cooled.

Cracks do not appear to be more numerous in this specimen than in the one cooled in air. The effect of the water has been to produce, either large cracks which pass entirely through the block, or very small ones on the surface. The slide was made of material taken from the interior, hence no marked increase was to be expected. The inclusions are similar in amount and arrangement to those in the air-cooled specimen. The cracks are not related to the inclusions.

750° C., air-cooled.

The slide contains a great many cracks, and the minerals are shattered, the quartz especially so. Some of the crystals of the latter are free from inclusions of gases and liquids and yet are full of cracks. Others contain many lines of inclusions, but they are not genetically related to the cracks. No moving bubbles were found. Under crossed nicols the quartz shows a shadowy strain effect, but it is very poorly developed.

750° C., water-cooled.

On the whole this block is more shattered than the air-cooled one. The quartz shows this especially well. It is full of inclusions, arranged in lines and disseminated, but the cracks it contains are not necessarily controlled by their position except when the inclusions are very abundant and in a line, in which case the crack may follow them a short distance. They run in all directions.

Material from the Missouri Granite Construction Company, Knoblick, Missouri

500° C., air-cooled.

The quartz contains a great many inclusions, usually in nearly straight lines. The lines of inclusions in adjacent crystals are sometimes parallel. The inclusions are mainly of liquid and gas. The

cracks cross them at all angles and are not genetically related to them.

500° C., water-cooled.

The quartz, especially that of the larger crystals, contains a good many cracks. Occasionally one is along the lines of inclusions, of which the mineral contains a great many, but the majority of the cracks do not follow such lines of inclusions. Some of the quartz contains some very small, parallel, incipient cracks. These may or may not cut through the inclusions. Occasionally they make an angle of 120° with each other. The inclusions are largely gaseous, with some liquid ones. No moving bubbles could be found.

750° C., air-cooled.

All the minerals on the slide are greatly shattered. The feldspar shows a widening along the cleavage planes. The quartz is especially shattered. It usually contains many inclusions in rows, some as broad, heavy lines. Cracks follow these larger lines of inclusions but they change their direction without regard to the line of inclusions they may be following. The cracks are just as numerous in those crystals of quartz which do not contain inclusions or in which they are disseminated. Many broad lines of inclusions are free from cracks entirely. The incipient, parallel cracks are larger and more abundant than in the block heated to 500° C. They are as common in areas free from inclusions as in those which contain them.

750° C., water-cooled.

The quartz of this specimen contains the usual amount of inclusions, both in lines and disseminated. There are some grains quite free from scattered inclusions. The cracks run in all directions and may follow a row of inclusions or may cross it at all angles. Incipient, parallel cracks are developing in some of the crystals of quartz. They may cut across a cavity, for they are often in quartz which is full of inclusions. The inclusions do not appear to be changed by the crack.

Material from the Milne and Gordon Quarry, Knoblick, Missouri

500° C., air-cooled.

A slide of the material from the outside of the block and one of the material from the interior were made from this specimen. The quartz is quite full of dark inclusions, in rows and scattered, which are largely gaseous, but some liquid, and some mineral inclusions

occur. The quartz shows only a few cracks and these have no relation to the position of the inclusions.

500° C., water-cooled.

The quartz contains as many inclusions as there are in the above slides, but it is very much shattered in this one. The cracks run in all directions and are not connected genetically with the inclusions.

750° C., air-cooled.

The two cubes heated to 750° C. fell to pieces when touched with the tongs to remove them from the furnace muffle. Both were air-cooled. Slides were made of the outside and inside material, but there is no difference between them. The quartz contains many inclusions, the majority of which are gaseous or liquid, with some mineral inclusions. There are some parallel, incipient cracks in quartz which is with or without inclusions. Some of these cracks are very well developed, in fact, better than in any of the slides. The larger cracks sometimes follow the inclusions but they also cross them.

Material from the Gilsonite Quarry, Knoblick, Missouri.

This material was tested because it was fine-grained. Only two slides were made.

500° C., water-cooled.

All the minerals in this specimen are very small. The quartz contains only a few inclusions, which are disseminated and in rows. Cracks are fairly numerous but they cut across or around the grains. They usually do not follow the lines of inclusions.

750° C., water-cooled.

The inclusions in this specimen are the same as in the above slide. The cracks are about the same, save a majority of them go around the grains rather than through them.

Material from Graniteville, Missouri

The following slides were made from some fragments of the Graniteville granite. It was not intended that slides should be made of them when they were heated, but the temperatures were carried to 850° C. and 900° C., so it was decided to do so, to compare the results with those obtained from heating to lower temperatures.

850° C., air-cooled.

The quartz contains the usual inclusions, gaseous and liquid with some mineral ones, arranged in rows or disseminated. The cracks are very numerous, but their directions are not controlled by the lines of inclusions. They pass in all directions through the quartz. A very interesting feature, seen for the first time in this slide, is the wavy extinction of the quartz and feldspar. It is wonderfully well developed in the quartz, and fairly well in the feldspar. It is due to the strains produced in the mineral by the high temperature.

850° C., air-cooled.

The wavy extinction seen in the slides described above, occurs in this one also. The inclusions are the same as usual. The quartz is much more shattered than in any other slide studied. The fragments range in size from .078 mm. to .266 mm. or larger. Probably from fifteen to twenty-five per cent of the cracks follow the lines of inclusions. This is to be expected for the quartz is broken up into smaller fragments than has been heretofore seen. The feldspar shows cracks developed along the cleavage lines. The cracks become very irregular when they are in a feldspar crystal that is much altered to kaolin.

900° C., air-cooled.

The wavy extinction and shattering are prominent features in this slide as they were in the last one described. The quartz is very much granulated, and even the feldspar is so, along its contact with other minerals. While the minerals are shattered, only a part of the cracks follow the rows of inclusions.

900° C., water-cooled.

This slide shows essentially the same features as the other one which was heated to 900° C. Inclusions are the same as in the other rocks, and are not genetically related to the cracks.

SUMMARY

The microscopic study of thin sections shows that the moving bubbles have disappeared in the heated sections, and that the inclusions which contained gases and liquids, are darker and have broader margins. The cavities which contain liquids and gases are just as numerous as in the unheated specimen and are arranged in the same way. They do not show cracks associated with them. The quartz

shows many cracks which run through it in various directions but which may or may not follow the lines of inclusions. Incipient, parallel cracks have developed in the quartz. They are probably along the cleavage lines of the quartz. They often cut through an inclusion but do not produce a change in it. Both of the above types of cracks are just as common in the quartz which does not contain any inclusions as in that which does.

CHAPTER IV

THE CAUSE OF THE DISAGGREGATION OF THE GRANITE

That there was a great loss of strength, when the granite was heated to high temperatures, is indicated by the tables and the curves, which show the results of the strength tests. The decrease in strength was greater up to 500° C. than afterwards, but the rock was completely destroyed at 1000° C. The greatest resistance to high temperatures was shown by the fine-grained granites, while the coarse-grained ones, like the Graniteville granite, was the least resistant. An apparent exception to this statement is the granite from the Milne and Gordon Quarry, which was destroyed at 750° C.

Further evidence of the disaggregation is found in the cracks and fractures which are developed by the heating. Some of the cracks are large and continue entirely across the face of the cube, while others are not so prominent, being only an inch or so long. Many cracks are developed at the contacts of the minerals with each other, and there are some which are confined to the individual minerals. These last are usually small, and take advantage of the planes of weakness already existing in the mineral on account of its molecular structure, such as cleavage and twinning planes. While the unheated rock shows a few cracks they are not nearly so numerous as in the heated ones. The quartz in the fresh rock is usually more shattered than the feldspar, although this may not be really the case, as the cracks are readily seen in the quartz, and with difficulty in the feldspar. The quartz in the water-cooled cubes is nearly always greatly shattered on the surface. This shattering is not so prominent in the quartz in the interior of the cube, which points to a probable connection of the cracks with the sudden cooling by the water.

Another evidence that the rock is weakened by heating is the strained condition that is indicated by the wavy extinction of the quartz and feldspar in the specimens heated to 850° C. or above. While this feature is not shown by those heated to 750° C. or less, it is evidence that the heat was probably producing similar strains at lower temperatures, and thus aiding in weakening the rock. The ringing sound emitted when the heated cube is scratched is believed to show the tension, due to permanent expansion, under which the minerals exist in the heated specimen. The sound has a marked ringing note in those specimens which contain numerous small cracks, but is dull in those where larger ones have developed. Some of the cubes heated to the higher temperatures are so friable that they can be crumbled with the fingers.

The results of the tests indicate, then, that the granite cannot withstand more than a moderate heat without becoming weakened.

While it is always necessary to have various tests made on rocks used for building and structural purposes in order to determine their various physical properties, the results of the data so obtained are subject to interpretations which depend upon the completeness of the data. In the series of tests and studies described in this bulletin, data as to the cause of the marked loss of the strength of the granite on heating was sought. The data which was obtained is given above. As stated in the beginning of this paper, the cause must lie in the individual mineral components of the rock, and in their relationship to each other. It becomes necessary to evaluate each factor, and to determine whether the real cause lies in the individual and in their relationships, or whether the results are the cumulative effects of the individual minerals uniting in the whole effect.

The Effect of Molecular Structure

This study is simplified by having only two minerals, quartz and feldspar, to deal with in most of the rocks. The minerals are all more or less cracked, as a result of the heating, as is shown by the study of the heated blocks, and by the microscopic study of the slides. In the feldspar the cracks are controlled by the molecular structure of the minerals, such as the cleavage, twinning planes, etc. When it is altered to a mass of kaolin, the cracks are no longer controlled by the molecular structure. As feldspar has good cleavage in two directions, the cracks would be expected to be rather abundant, and they are found to be so.

Quartz, on the other hand, is usually regarded as being massive, but it does have a very good cleavage parallel to the pyramidal face *r*. This cleavage face is very rarely seen. (The writer remembers having seen a large crystal of quartz, which had been heated, that showed cracks which were parallel to the face mentioned above.) The incipient, parallel cracks, that have been mentioned in the description of nearly every slide, and also in the description of some of the cubes, are interpretated to be along the cleavage lines. They were more prominent and larger on the surface of some of the cubes, because there, when the quartz crystal was lying with its long axis parallel to the surface, the cleavage planes would make an angle with the surface which was favorable for the expansion of the mineral. This expansion probably developed the cracks.

Besides this cleavage in one direction, there is no other physical property of quartz which would control the direction of a crack or fracture. There is another factor here, however, which must be recog-

nized, and that is the presence of inclusions in the quartz. They consist, as has been stated above in the descriptions of the Missouri granites, of various minerals in small amounts, and of numerous cavities, which contain liquids and gases. The most common of these are water and carbon dioxide, both of which may exist in the quartz in a liquid or a gaseous state. These inclusions were incorporated in the quartz at the time of its solidification. They may be scattered throughout the quartz, or they may be in lines or rows which are usually more or less curved. A few of these lines were found to be approximately parallel to the cleavage direction of the quartz mentioned above. Occasionally they cross from one grain to another, which probably means that the two grains were formerly part of a single crystal. The inclusions vary greatly in size. The study with the binocular microscope showed that the inclusions were really in planes.

Since this is the case, these planes of inclusions should be planes of weakness, and the cracks should follow them, whenever their position or direction was such as to enable them to take advantage of the plane. Not only should the planes be weaker because of the presence of the inclusions, but it has been suggested, that those which contain liquids and gases, under high temperatures would exert a very great pressure upon the walls, (great enough to burst them, according to some men), and this pressure should aid in weakening them. Any other inclusions present are not believed to play a very important part in the weakening effect, although any expansion they undergo will help.

Laying aside for a time the question of the effectiveness of the materials in the cavities, we must consider whether there is a relationship between the cracks, as observed in the quartz, and the lines of inclusions. The answer must be largely negative. The great majority of the cracks cross, at any angle, the lines of inclusions which they encounter, in fact, they are often parallel to the cracks, and but a fraction of a millimeter away. It must be understood, however, that while this is true of a majority of the occurrences there are cracks which follow the lines of inclusions, often for several millimeters. This was noticed especially in the case of a few of the large lines. The more numerous the cracks, the more apt they were to follow the lines. In view of the fact that the line of inclusions should be expected to be a line of weakness in the quartz, it is surprising how many of the cracks cut across them. In many crystals of quartz there were no lines or rows of inclusions; they were disseminated throughout the crystal. These crystals were cracked just the same as those with the inclusions in lines, the cracks running in any direction.

The above facts show that the lines of inclusions do not influence the position of the cracks but what is even stronger evidence, although

negative in character, is that the quartz which is free from inclusions contains just as many cracks, and of the same general character, as those in the inclusion-rich quartz. This would indicate that the cracks could develop independently of the inclusions. Another feature along these lines was the presence of small radial cracks often only a millimeter or less in length, along the margin of the quartz grains. They did not reach the lines of inclusions on the interior. They were seen only on the polished surface, and probably owe their origin to the expansion and contraction of the quartz while cooling.

The conclusion must be, therefore, that the molecular structure of the mineral largely determines the direction of the cracks developed in it and that the lines of inclusions are very minor factors in the location of the cracks.

The Effect of the Fluidal Inclusions

The presence of gases and liquids in the cavities of the quartz has been noted above. They are very minute, rarely over .02 mm. in diameter and usually much less. One was measured which was .0027 mm. in diameter. Hull estimates that the cavities in some quartz crystals are so small that from 1 to 10,000 million could be contained in a single cubic inch of space.[8] The "moving bubble" which is found in so many of them is, of course, much smaller. The total amount of the inclusions of all kinds in the quartz is estimated to be about one per cent, which may be incorrect fifty per cent either way. From fifty to seventy-five per cent of the inclusions are fluidal cavities so their amount is very small. It is the opinion of other men who have studied them in other rocks, that the inclusions comprise a very small percentage of the quartz. Quantitatively, then, the effectiveness of the included gases and liquids would be small, even when heated to very high temperatures.

It has been stated above that not a single moving bubble was found in the heated granite, so we must consider what became of them. There are two possibilities: one, that the gas in the bubble has escaped, and the other, that the liquid in the cavity with the bubble has been converted, in part at least, into a gas. In either case the "moving" bubble would disappear.

For the gas to have escaped it would be necessary for it to rupture the confining walls. If it had force enough it might do this, or it might be aided by the development of a crack by outside agencies, the crack penetrating its walls. The contents of those inclusions along the cracks have escaped, as a matter of course, but the vast majority of the cavities show absolutely no sign of a crack, or even a strain

8. Hull, E., Bldg. and Ornamental Stones, 1872, p. 30.

effect in their walls or near them. This, then, is taken to mean that the gaseous bubble has not escaped; it has not burst its walls, thus shattering the quartz, and hence the granite.

As to the second possibility, it has been mentioned in the descriptions, that the cavities are darker in all the heated specimens, and that their margin is broader. This is a characteristic of gaseous inclusions, and it is believed that part of the liquid may have been converted wholly, or in large part, into a gas by the high temperature, and that liquifaction has not yet resulted, if, in fact, it ever does. The boundaries of the cavities are as distinct as they were before heating, and many of the larger cavities still retain a large, immovable bubble.

Hence the conclusion is, that the liquid and gaseous inclusions in the quartz have no influence on the development of the cracks, and thus on the consequent disruption of the granite.

The Effect of the Unequal Expansion of the Minerals.

The above discussion has shown that the granite is greatly weakened by heating, and that the development of numerous cracks has been the chief physical change. The cracks were controlled mainly by the molecular structure of the given mineral and only to a very minor extent by the inclusions. The character of the inclusions had no influence on the direction of the cracks. The cause that produced the cracks was undoubtedly the unequal expansion of the different minerals in the rock. Clarke gives the cubic expansion of quartz as .000036 per degree, and of feldspar as .000017.[9] Thus quartz has more than twice as great an expansion as feldspar and consequently very unequal stresses are set up when a rock which contains these two minerals is heated to high temperatures. The linear expansion of minerals is unequal along the different axes in the same mineral. Clarke gives the following values for quartz. On the c-axis the expansion is .000008073, along the a-axes it is .000015147, the ratio being nearly 1:22. For feldspar (adularia, a transparent variety of orthoclase) the values are different along the three axes at right angles to each other and have the following values: .000015687, .000000659, and .000002914, the ratios being 23.6:1:4.4. Thus we find that the feldspar expands nearly twenty-four times as much along one axis, as along that of the least expansion, and 4.4 times as much along another. Here there is a source of great tension which will produce severe strains in the minerals and the rock. If the rate of expansion holds

9. Clarke, F. W., Smithsonian Miscellaneous Collections., Vol. 14, No. 289, p. 17.

for the higher temperatures, the amount of cubic expansion at different temperatures for the quartz and feldspar are as follows:

	500° C.	750° C.	1000° C.
Quartz	.018	.027	.036
Feldspar	.0085	.0128	.017

Likewise, if the same rate of linear expansion holds at the high temperatures, the values for the different temperatures for quartz and feldspar are as follows:

	500° C.	750° C.	1000° C.
Quartz			
c-axis	.004	.006	.008
a-axes	.0076	.0114	.0152
Feldspar			
Three axes	.0078	.0118	.0157
at right	.00033	.0005	.0007
angles.	.0015	.0022	.0029

These figures are regarded as being of value only in indicating the general character of the amount of expansion. They show that the heating must produce very severe strains in the rock, which find relief in fracturing the rock and thus causing it to become weakened. The permanent expansion of the rock indicates the same result. The average permanent expansion in a block about seven and one-half inches long, heated to 500° C. is .00483 inches, and for a similar block heated to 750° C. it is .01299 inches.

The effect of sudden cooling by plunging in a stream of cold water was felt primarily on the exterior of the block, and only secondarily on the interior. The rapid cooling of the outside caused it to contract more than the hot interior, and thus developed the cracks in the outer part. The size of the crystals in the rock would become a factor here, the fine-grained rock transmitting the heat faster than the coarse-grained. This may be a partial cause of the greater strength and resistance of the fine-grained rocks.

On the whole it is seen that the heating must produce strains in the rock which find relief in fractures. These strains vary in different directions in the minerals and thus intensify the effect. The result is a series of cracks and fractures along lines of weakness in the minerals themselves at their contacts with each other and through them in any position. This greatly weakens the rock and may destroy it.

There is still another factor which may aid in the disaggregation of the rock. This is the property of quartz to change into another form at certain temperatures. Quartz, which has solidified at a temperature less than 575° C. is called alpha-quartz, and on being

heated above this temperature changes into beta-quartz. This change is accompanied by a permanent expansion of the mineral and by a shattering. Further heating to 870° C.,[10] in the presence of a suitable flux, slowly changes the quartz to tridymite but if no flux is present it does not change until 1400° C.,[11] or higher, is reached.

As most granites are thought to have cooled at temperatures above 575° C., the lower change is not probable in our study, and the temperature necessary for the last change was not reached in our series, save in the case of the Graniteville material. The other condition, that is, the necessary flux, was lacking also. The strain effects noted at the higher temperatures are not due to the tendency of the quartz to invert into another form, for they are in the feldspar as well as in the quartz.

When the study was begun it was decided to use temperatures of 500° C. and 750° C. in order to remain below these inversion points. These temperatures are sufficiently high to greatly weaken the stone, and so are believed to be satisfactory. The changes which the quartz undergoes at these temperatures are those due to its unequal expansion, just as are those in the feldspar. Hence the change of quartz into another form is not believed to be influential. The expansion of the rock as a whole produced numerous strains between the cooler and the hotter portions, and aided in the development of the larger cracks. It is these larger, cumulative strains that produce the spalling off of fragments from larger blocks. This spalling was very noticeable in the large blocks used in Humphrey's fire tests for the government.[12]

10. Wright and Larsen, Am. Jour. Sc. 4th series, 27: 421: 1909.

11. Fenner, Wash. Acad. Sc. 1-2: 472: 1911-12. Johnston, John, Jour. Geol. 21: 497: 1913.

12. Humphrey, R. L., Bull., 370, U. S. G. S.

CONCLUSIONS.

The loss of strength by the Missouri granites, on heating, is due to the differential stresses that are set up in the individual minerals, because their expansion differs widely along the crystallographic axes. To this is added the strain due to varying temperatures in different parts of the block.

The presence of numerous inclusions, especially liquids and gases, in the quartz is regarded as not having any effect upon the resulting disaggregation, except in so far as a series of inclusions of any nature arranged along a plane in a mineral would make that plane a line of weakness in it.

The temperature is not high enough to cause the quartz to invert into another form, hence the physical change involved in this inversion is not a factor in the disaggregation of the granite.

CHAPTER V

PRACTICAL CONSIDERATIONS

The studies that are described in this bulletin are of practical value in several ways. The most important of these is the determination of the loss of strength on heating to high temperatures. At the same time, it was of value to determine the effect of various temperatures upon the granite. The tests give the strength of several more granites than have been available heretofore. The effects of slow cooling in air and sudden cooling by water are also noted. The practical application of these various tests will be discussed.

Since all structures utilized by man in his home and industrial life are in danger of fires it is of value to know something of the fire resisting properties of the materials used in the structures and whether they are active members of the structure or are merely ornamental. In the former case it is expedient, because that material should be used which is least liable to be completely destroyed or seriously damaged; in the latter case, if the material is seriously damaged, there is a total loss.

Granite is used extensively in all building operations, but not so extensively for ornamental purposes, largely because it costs much more to prepare it for the desired use, than it costs to prepare marble or serpentine. This is because of the greater hardness of the granite. There are many granites on the market today that are far more beautiful than some of the marbles used for interior decoration, and they would doubtless be used for this purpose if it were not for their higher cost.

Other men have usually stated that granite is not very fire resistant and that it is seriously damaged, if not totally destroyed, by even a moderately hot fire. While the tests described here were not made as a comparative study, they indicate that granite does lose a large part of its strength at comparatively low temperatures, about 36.4 per cent below 500° C. and 62.4 per cent below 750° C. The effects of the tests made are not so severe as they would be if larger cubes had been used. It is the minerals which are affected, rather than the cube as a whole, for the larger cracks are produced by the cumulative stresses developed by the minerals. In the small cube these mineral stresses were relieved by the expansion of the cube as a whole, for it soon became heated throughout, while in a larger block some portions would be at a different temperature for a longer time so that larger stresses would develop between the cooler and hotter portions

and find relief by fracturing the rock. This might occur during the heating or afterwards during the cooling. Spalling is especially liable to develop under these conditions. If the fire lasts for a considerable length of time, the spalling would completely destroy a granite column. Therefore, when the marked loss of strength in the cubes, due to heating, is applied to larger sized material, the damage would probably be much greater. Even if the damage in a larger block was no greater than in the small cubes the results indicate that the stone would be made worthless.

The texture of a stone is of importance in resisting the damage, due to the heat. The fine-grained rocks in the sets are the most resistant, showing the highest crushing strengths after heating. Other investigators state that the coarse-grained rocks are less resistant.

The mineral composition is not so very important. The Missouri granites consist mainly of quartz and feldspar, with small amounts of other minerals. In general, the coarse-grained granites contain the most quartz, averaging about four per cent more than the fine-grained ones. However, the size of the crystals of each of the minerals is far more important than their relative numerical proportions. McCourt (Op. cit.) found that a syenite with very little quartz was as badly injured as were the gneisses that he tested. The texture of the rocks was more important. Dodge tested some Minnesota syenites and found that all were damaged but that the coarse-grained ones suffered the most.[13] The conclusions, resulting from this study, which maintain that the inclusions in the quartz do not affect the strength of the granite and are not a factor in its disaggregation, are supported by these facts.

The crushing strength of seven different Missouri granites was determined. These values are higher than those of the three different granites given by Buckley and Buehler in their report on the quarrying industry of Missouri.[14] This is due mainly to the fact that the cubes used in our tests were more perfect than the ones they used. The average of the crushing strengths of all the cubes tested in our work is 29,260 pounds per square inch. The minimum crushing strength is 25,100 pounds per square inch, and the maximum is 34,960 pounds. These values, especially the average, are well above the values of Wisconsin, Minnesota, and Washington granites given by the above authors on page 323 of their report. These values are fully equal to the average strength of the granites in the eastern part of the United States. The results show that, in respect to their crushing strength, the Missouri granites are the equal of any in the United States, and

13. Dodge, J. A., Minn. Geol. Sur. Vol. I, : 186; 1882.
14. Buckley and Buehler, Mo., Bur., of Geol. and Mines, II, 2d series: 313.

are suitable for usage where the rock is required to support great weight.

The effects of cooling in air and in water indicate that the damage to the granite by cooling in water is not so serious as is generally thought. Some of the sets cooled in water showed greater strength than those cooled in air, as is shown above on page 22. The damage to large blocks, however, would be far more serious than in the small cubes on which these tests were made.

High temperatures are found to be very damaging to the Missouri granite, its strength at 750° C. being only about two thirds of what it is in the fresh granite. Mineralogical composition has little effect on the resulting loss of strength, but the texture is very important, the fine-grained varieties being the most resistant to heat. The average strength of the several Missouri granites is high.

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ENGINEERING EXPERIMENT STATION SERIES 16

THE ECONOMICS OF ELECTRIC COOKING

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CONTENTS

The Economics of Electric Cooking

INTRODUCTION

The present status of electric cooking might be compared in a way with the condition of electric lighting about 1890. Electric lighting had then passed beyond the experimental stage and was used commercially but no exhaustive study had been made of the science of illumination with a view to obtain the greatest efficiency. Today, electric cooking has passed beyond the experimental stage and is used commercially, but as yet no study has been made of the variable conditions affecting this work, or the combination which will produce the greatest efficiency.

The first electric light fixtures were obtained by wiring the gas fixtures then in general use. Afterwards special types of fixtures were developed which were more adapted to the use of electricity. Similarly, the first electric ovens were obtained by replacing the gas burners of a gas oven with electric heating coils. Some further improvement has been made by adding heat insulation, but as yet little attention has been given to the proper conditions of cooking which make for greatest convenience and economy in operation. With inefficient stoves and cheap fuels the need of such an investigation has not been apparent. Since in a coal range only a very small percentage of the heat energy in the fuel is absorbed by the food, it makes but little difference whether a particular article of food is cooked for half an hour at 200°C. (392°F.) or for one hour at 150°C. (303°F.) as long as the final quality of the food is satisfactory.

It was the purpose of the investigations which form the basis of this article to study the operation and the design of electric ovens with the view to determine some of the factors which will increase the economy and hence the popularity of electric cooking. While the actual results here presented are not as definite and illuminating as hoped for, yet it is believed they will not be without practical value as a contribution to what is a very complex subject.

Particular attention is called to the fact that much of the information contained herein is made easily available to the understanding by the use of plotted curves.

DESCRIPTION OF OVENS USED IN THE TESTS

In order to determine the amount of energy used in electric cooking and the best methods of preparing various articles of food for an electric oven, tests were made on three commercial and several

experimental ovens. Each commercial oven was selected as representing a general type of electric oven in use for domestic cooking.

Fig. 1

Fig. 1 shows a large range suitable for a good sized family. The inside dimensions of the oven are 18 inches by 12 inches by 12 inches. Two heating units are used, one in the top and one in the bottom of the oven. Each unit consists of two heating coils controlled from a snap switch on the front of the oven so as to consume 220, 440, or 880 watts continuously. From one to two inches of mineral wool is used as heat insulation. The outside surface of the oven is blued steel and it is finished with nickeled legs and trimmings. The oven door is 12 by 18 inches and 1.5 inches thick. It fits tightly and clamps securely in place when shut. Three heating units are also placed on top of the range for cooking not done in the oven. Fig. 2 is a cross section of the oven thru the center, showing the position of the heating coils and the thermo-couple used to measure the temperature in these experiments.

Fig. 3 shows a small, well-insulated oven (No. 2) suitable for a small or medium-sized family. The inside dimensions of the oven are 9.5 inches wide, 10 inches deep, and 12 inches high. The inside finish is seamless drawn aluminum and the outside is blued steel with nickeled trimmings. Two and one-half inches of mineral wool is used for heat insulation. An ironclad heating element is placed in the bottom of the oven. This heating element consumes continuously 500 watts when connected to a 110 volt circuit. The heat cannot be turned

partly off as there is only one heating element. There is no heating unit in the top of the oven. Underneath the oven is an automatic temperature control which may be set at various values by means of a dial. The dial is graduated in arbitrary numbers from 1 to 11. When

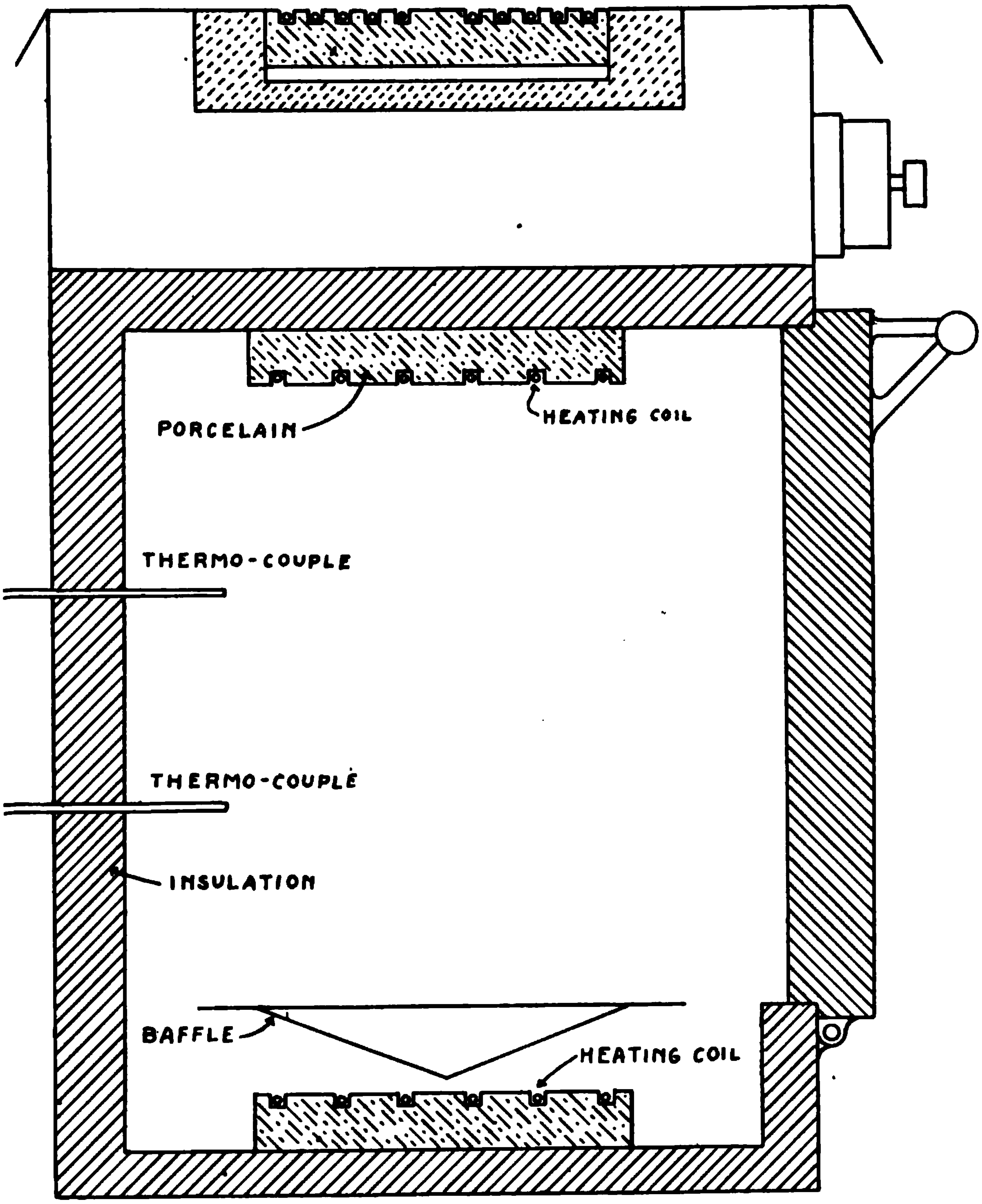


FIG. 2 CROSS-SECTIOIN OVEN NO. 1

the handle of the dial is set at a given number, a thermostat will open the circuit of the heating element as soon as the inside of the oven has reached a temperature corresponding to the given number. As the oven cools, the thermostat must be reset by hand by pushing the handle

of the dial. Fig. 4 is a cross section of the oven thru the center showing the position of the heating coil and the thermo-couple used in the experiments.

Fig. 5 shows oven No. 3, one of the well-known makes of fireless cookers with a heating element placed underneath the inner lining.

Fig. 3

The inside dimensions are 10.5 inches deep and 11.5 inches in diameter. The inside lining is seamless aluminum and the outside finish is varnished oak. The sides and bottom are insulated with powdered kieselguhr, while the cover is insulated with granulated cork. Fig. 6 is a cross section of the oven showing the heating coil and thermocouple. This oven uses 500 watts on 110 volts. There is no method of turning the energy partly off.

Oven No. 4 was built by the Engineering Experiment Station. The inside dimensions were the same as oven No. 2. A 440, 880-watt heating unit was placed in the bottom of the oven and a 440-watt unit in the top as shown in Fig. 7. Sheet iron was used for the inside lining of the oven. A 4-inch layer of a commercial brand of diatoma-

ceous insulating brick was used for insulation. Later four inches of cork board was added as shown in the drawing. This was put on with cement and no outside covering was used except on the front and the door, which were covered with wood.

FIG. 4 CROSS-SECTION OF OVEN NO. 2.

APPARATUS USED

The energy used was measured by means of indicating watt meters calibrated by comparison with Weston laboratory standards, and by an induction watt-hour meter calibrated at frequent intervals by comparison with a rotating standard.

The temperature of the ovens was measured by means of copper-constantan thermo-couples with which an accuracy of 0.1 degree is obtainable when used below 360°C.[1] (680°F.). A Siemens-Halske indi-

1. Adams and Johnson. Am. Jour. of Science, June, 1912.

cating galvanometer and a Bristol recording galvanometer were used to determine the e.m.f. of the thermo-couples. The recording galvanometer traced a curve by intermittent contact on a circular smoked chart. Both the indicating and the recording galvanometer were calibrated for the copper-constantan thermo-couples by means of mercury thermometers which had been certified by the Bureau of Standards. The thermo-couple and the thermometer were immersed in an oil bath which was slowly heated and carefully stirred. Simultaneous readings were taken of the galvanometer and the thermometer. Fig. 8 shows a

Fig. 5

diagram of the connections used for the galvanometers and thermocouples.

In the oven the wires of the thermo-couple were enclosed in a glass tube and separated by mica. Outside the oven they were enclosed in rubber tubing. The cold junction was kept at 0°C. (32°F.) by immersion in ice water.

In oven No. 1 an extra thermo-couple was inserted for measuring the internal temperature of the food. The wires entered the oven thru two glass bushings and were left bare except for a 3-inch glass tube at the end which was inserted in the food. The wires were long

enough so that after the food was cooked it could be placed on a shelf just outside the oven to cool without removing the thermo-couple from the food. In order that the wires would not short circuit either on themselves or on the lining of the oven all the slack was pulled outside the oven.

FIG. 6 CROSS-SECTION OF OVEN NO. 3

THEORY AND PURPOSE OF COOKING

In order to understand some of the problems which must be worked out before an ideal electric cooking device can be perfected, a word about the purpose of cooking food will not be out of place. The objects of cooking food are, briefly: (1) to render it more digestible so that the nutrient parts can be easily absorbed by the digestive organs; (2) to render it more appetizing by improving its appearance and developing in it new flavors; (3) to sterilize it to some extent thus delaying incipient putrefaction. The relative importance of these

objects depends upon the article of food which is to be cooked. For instance, in cooking animal foods the most important objects to be attained are to improve the flavor and appearance and to sterilize them. In fact, the cooking of animal foods such as meat, eggs, and fish which are rich in proteids actually decreases their digestibility. This is true at least of the chemical processes of digestion. The in-

FIG. 7 CROSS-SECTION OVEN NO. 4

creased attractiveness, however, of well-cooked food may render it indirectly more digestible by causing a greater flow of the digestive juices.

The effects of applying heat to various foods can be more easily understood by first considering the effect of heat on the various chemi-

cal constituents of which protein, starch and fat are the most important. The effect of heat on the protein of foods is to coagulate it. This change occurs at the comparatively low temperature of 75°C. (167°F.). If the temperature is increased much above this point the protein tends to shrink and harden, and the digestibility of the food of which it is a part is proportionately lessened. This fact can be easily demonstrated in the case of the white of an egg. If an egg cooked for ten minutes in water at a temperature of 75°C. is compared with one cooked in the ordinary way, that is, for three minutes in boiling water, it will be found that the albumin of both are solid thruout, but in the case of the former it will consist of a tender jelly, whereas in the boiled egg it will be dense and almost leathery.

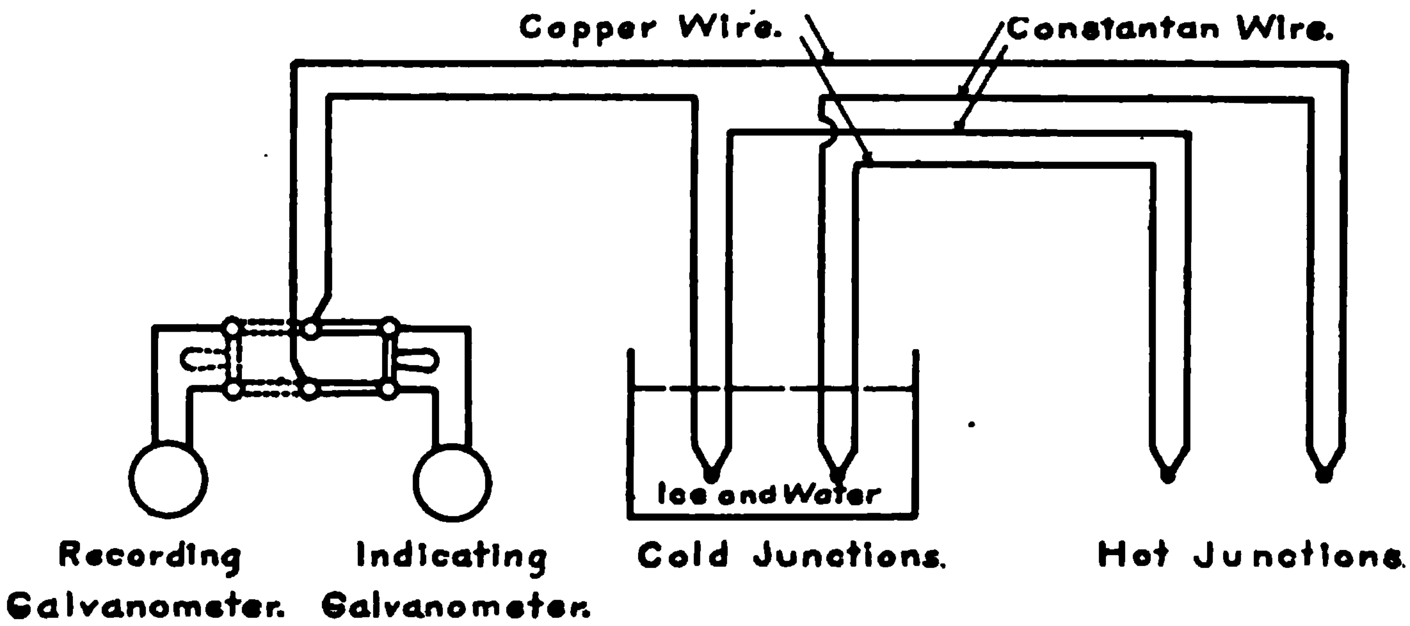


FIG 8. CONNECTIONS OF THERMO-COUPLES AND GALVANOMETERS

The investigations of Meyer,[1] Harcourt,[2] and Day[3] demonstrate that starch consists of microscopic grains or cells which are but slightly soluble in cold water. These grains are composed of layers. The inner and outer layers have distinct properties. The inner layers, called blue amylose because of the color which they give with iodine, are very slowly digested in the raw state. They take up water at from 60° to 80°C. (140° to 176°F.) and form a sticky collodial substance known as starch paste, in which form the inner portion is very easily digested. Long boiling to the extent of three hours does not make it more digestible. The outer layers of the starch (called red amylose) give a red color with iodine, and are more difficult of digestion or change in water than the inner portion of the starch grain. When starch paste is made without boiling, the outer layer stretches tho it

1. Untersuchungen über die Stärkehörner, Jena, 1895, p. 107.
2. Ann. Rpt. Ontario Ag. Col. and Exp. Farm 32, p. 63.
3. U. S. Dept. of Agr. Bul. 302.

does not break. In this condition it is easily permeable and does not interfere with the more rapid digestion of the inner portion. When starch paste is boiled Doctor Day found that a more homogenous tho not more digestible paste results. Dry heat at 150°C. (302°F.) or higher converts starch into a soluble form, and finally into dextrin. This change occurs to a limited degree in the crust of bread and in the making of toast.

In many vegetables and unground cereals the starch grains are enclosed in woody, fibrous, or cellulose walls which are but slightly affected by the digestive juices. The effect of cooking by the application of moist heat causes the starch grains to swell and to finally rupture the cellulose walls. This process occurs at temperatures much below the boiling point of water as shown by the values[1] given in Table I.

Table I.

Oats	85° Cent.	(185°F.)
Barley	80° Cent.	(176°F.)
Wheat	80° Cent.	(176°F.)
Rice	80° Cent.	(176°F.)
Maize	75° Cent.	(167°F.)
Potato	65° Cent.	(149°F.)

Since the fats of food are apparently but slightly affected by cooking,[2] their consideration is not of as much importance as protein or starch. The only change that has been detected in the composition of fats in cooking is a tendency to form free fatty acids at high temperatures (250°C.) (482°F.) which are thought to be irritating to the stomach.

The ideal preparation of food for human use requires that the nutrient which it contains shall be utilized to the fullest extent. Not only should the food be in such a state that the digestive juices can best act on it, but these digestive juices should be properly stimulated to do their work, by improving the taste or flavor of the food.

The present day problem is to determine the methods of cooking which will yield the most in nutrition and flavor with a minimum expenditure of fuel and labor. The solution of this problem will require careful research by the physiological-chemist, the domestic scientist and the manufacturer of cooking apparatus. Taking into consideration the results of experiments on the digestibility of foods cooked in various ways, the problem of the domestic science department is to definitely determine the range of temperatures and the

1. Sykes, Principles of Brewing, p. 70.
2. U. S. Dept. of Agr. Farm Bul. No. 526, p. 14.

time of cooking at each temperature for all classes of food. Effects of quality and proportion of ingredients, size of utensils, and other variables must be studied so that definite rules and tables can be worked out giving the most desirable times and temperatures of cooking any article of food.

The problem of the electrical engineer is to determine from the range of temperatures for cooking any given article of food, the particular temperature which is the most economical. He must also perfect an electric cooking apparatus which will maintain the desired temperature with a minimum amount of attention, and which will be low in first cost and economical in operation.

LOSSES OF ENERGY IN ELECTRIC OVENS

During the last century there has been a great advancement in the methods of applying heat to food. Each improvement has resulted in less of the heat energy being wasted and in more being absorbed by the food. Each step, from the open fireplace to the coal range, to the gas stove, and finally to the electric oven has been marked by the use of more expensive fuel, greater heat efficiency, and better control of the heat.

Except in a few localities, for the same number of heat units delivered at the meter, electricity is more expensive than gas or coal. Hence, it is only by studying carefully the most economical features of design and operation of electric cooking apparatus that electricity will be able to compete with gas and coal. A study of the heat losses in cooking is, therefore, of considerable importance to the designer of electric cooking apparatus.

Convection and Radiation Losses. If an electric oven is supplied with electric energy at a constant rate, say 1000 watts, the temperature of the oven will at first increase rapidly and then more slowly until it finally reaches a constant value. From the law of the conservation of energy it follows that if there is no food in the oven, the same amount of energy is lost into the room that is supplied by the heating coil. This heat is lost in two ways,—by radiation and by convection.

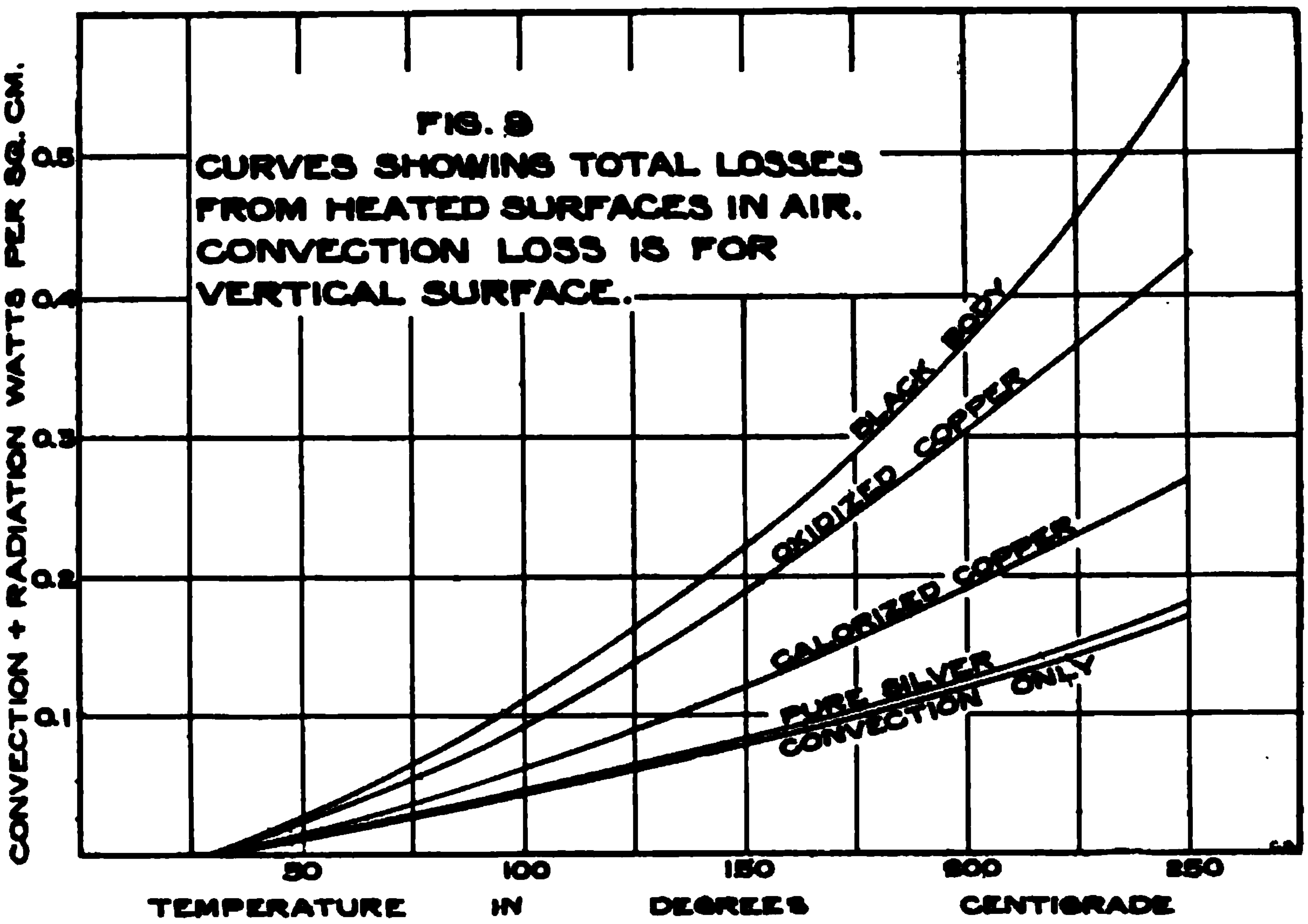
The radiation loss consists of waves of energy similar to light waves but of different length. The amount of the energy radiated depends upon the nature of the surface, its temperature, and the temperature of the room. It is independent of the shape of the radiating surface. The convection loss, however, depends upon the shape and the position of the surface as well as the temperature of the surface and the surroundings. It is independent of the nature of the surface.

The radiation and convection losses from horizontal and vertical plane surfaces have been determined by Langmuir[1] for various ma-

1. Trans. of Am. Electro-Chem. Soc., Vol. 22, p. 299 (1913).

terials. Fig. 9 shows the convection and radiation losses for vertical plane surfaces for temperatures up to 250°C. (482°F.), the highest temperature used in cooking. Fig. 10 shows the convection losses for vertical and horizontal surfaces as given by Langmuir.

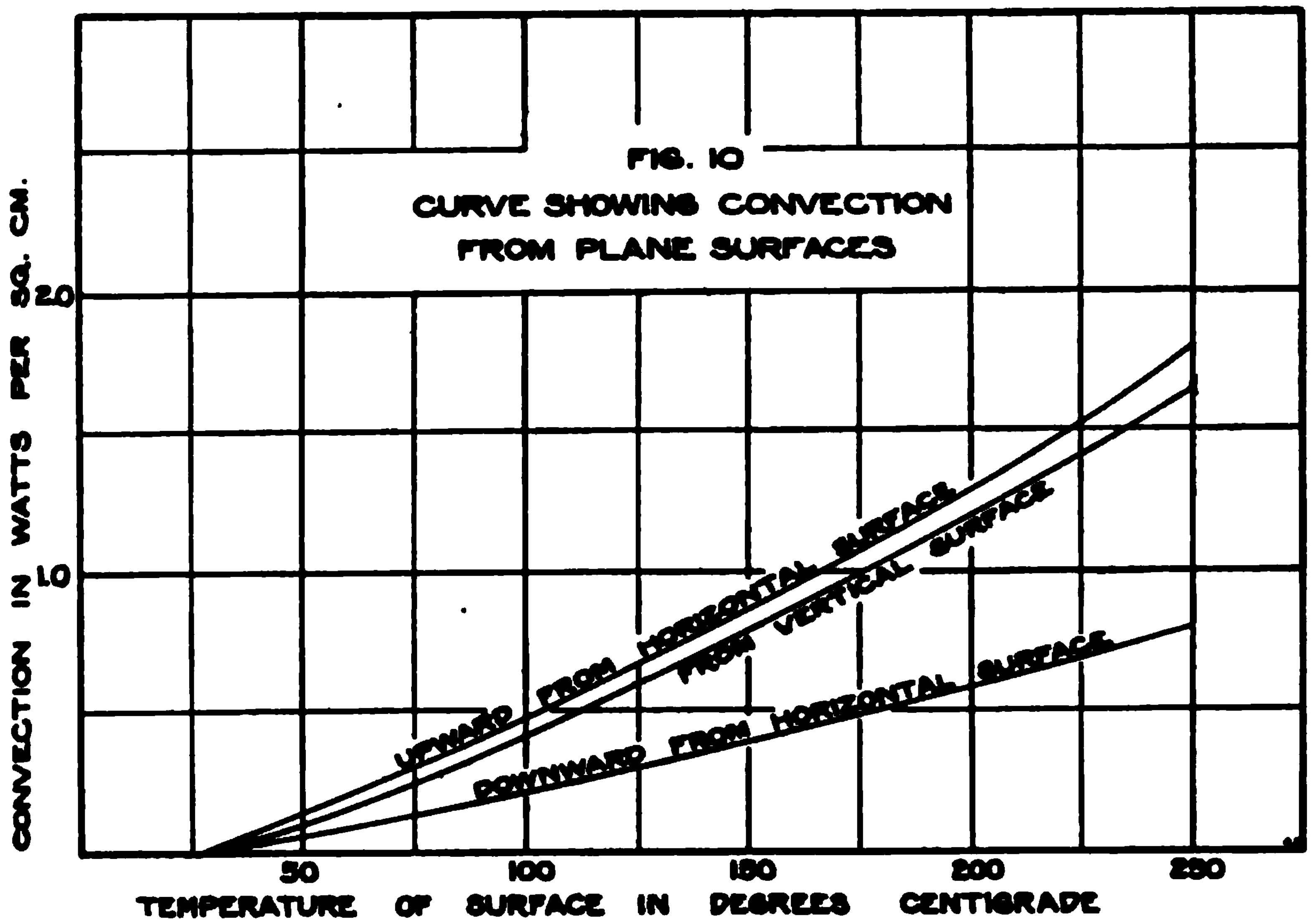
As shown by the curves the radiation loss from a black body constitutes a large part of the total loss, while the radiation from a polished silver surface forms but a small part of the total loss. For all other surfaces the radiation loss lies between that of a silver surface and a black surface; the convection loss being the same for all surfaces.



There are two ways in which the heat losses of an electric oven may be reduced. Consider an oven of given inside dimensions built on the plan of the ordinary gas oven, with a black outside surface and no heat insulation. The temperature of the outside surface will be within a few degrees of the temperature of the oven. A large amount of energy will be required to maintain a cooking temperature inside the oven. Since the convection and radiation losses depend on the temperature of the outside surface, the losses will be greatly reduced if this temperature can be decreased. If the inner and outer surfaces of the oven are separated a few inches and the intervening space filled with some poor conductor of heat such as mineral wool, kieselguhr, or diatomaceous earth, there will be a large drop in temperature between

the inner and outer surfaces, because the heat will be conducted away very slowly from the hot interior.

Suppose that enough heat insulation were introduced to reduce the outside temperature from 200°C. (392°F.) to 110°C. (230°F.), the watts lost per square centimeter of outside surface would be reduced from 0.37 to 0.12 as shown by the curves of Fig. 9. Stated in another way, the energy required to maintain the inside temperature of the oven at its former value would be reduced from 1000 watts to 325 watts for the same amount of outside surface. For the same inside dimensions, however, the area of the outside will be greater because of the



added insulation, hence the reduction in energy will not be quite in the proportion indicated.

Another method of reducing the heat losses would be to silver plate the outside surface of the oven. The heat loss would then be decreased from 0.37 watts per sq. cm. to 0.13, or the energy required to maintain the same inside oven temperature would be reduced from 1000 watts to 350 watts. By a combination of the two methods the input of the oven for the required internal temperature would be reduced from 1000 watts to 165 watts.

To silverplate the outside surface of an electric oven would be too expensive to be practical, but there are cheaper surfaces which radiate a very small amount of energy compared to the ordinary black oven. A white enameled surface, for instance, would be much more

efficient than the black surface. A place in which nickel plating could be used to good advantage would be around the edge of the oven door. Because of the good heat conductivity of the metal which connects the inner and outer surfaces of the oven around the door, the outside temperature of the oven is considerably higher around the edges of the door than elsewhere on the outside. If the nickel plating now used on the legs and corners of the stoves were put around the edge of the door, it would help to decrease the losses and the cost of the oven would be no greater.

The heat losses from an electric oven can be easily determined by measuring the energy input and the temperature in the oven after equilibrium conditions are established. The heat losses for the ovens tested were obtained in the following manner: A thermo-couple inside the oven was connected to a recording galvanometer. A given amount of energy was turned on so that the temperature of the oven increased until finally the heat lost equaled the energy measured by the wattmeter. The tests were continued until the oven temperature had remained constant for at least two hours. This was repeated for other values of energy input and curves were plotted between oven temperature and watts input as shown in Fig. 11. It will be noticed that the curves obtained are straight lines, all cutting the temperature axis at room temperature. Altho very exact measurements might show a slight upward tendency at higher temperatures, the present results with a maximum error of two per cent are sufficient for practical use.

Since the character of the surface and the outside area will remain constant for a particular oven, the above curves showing the relation between the oven temperature and the energy lost by radiation and convection should be similar to the curves given by Langmuir (Fig. 9). The apparent discrepancy can be accounted for in that the greatest outside temperature of the ovens tested was only 80°C. (176°F.) and below that temperature Langmuir's curves do not depart perceptibly from a straight line.

As will be shown later, the temperature energy curves of Fig. 11 are very useful in comparing the economy of various ovens for the cooking of any given article of food. Since one point of the curve will be zero energy at room temperature, only one determination is necessary to plot the curve for any particular oven. For a given room temperature measure the watts input and the temperature of the oven after it has become constant and plot this point on the diagram. Connect this point and a point on the temperature axis at room temperature with a straight line, and the heat lost from the oven at any given oven temperature may be directly taken from the diagram. These results indicate the energy lost thru the insulation and the metal around the edge of the door. To separate these items the energy

conducted thru the insulation can be directly calculated and subtracted from the total lost energy.

Preheating Losses. The heat losses of an electric oven may be resolved into those occurring before and those occurring after the food has been inserted in the oven. In many kinds of cooking, such as baking biscuits and cake, the food must be placed in a hot oven as soon as it is prepared. Since for domestic purposes an oven is never used con-

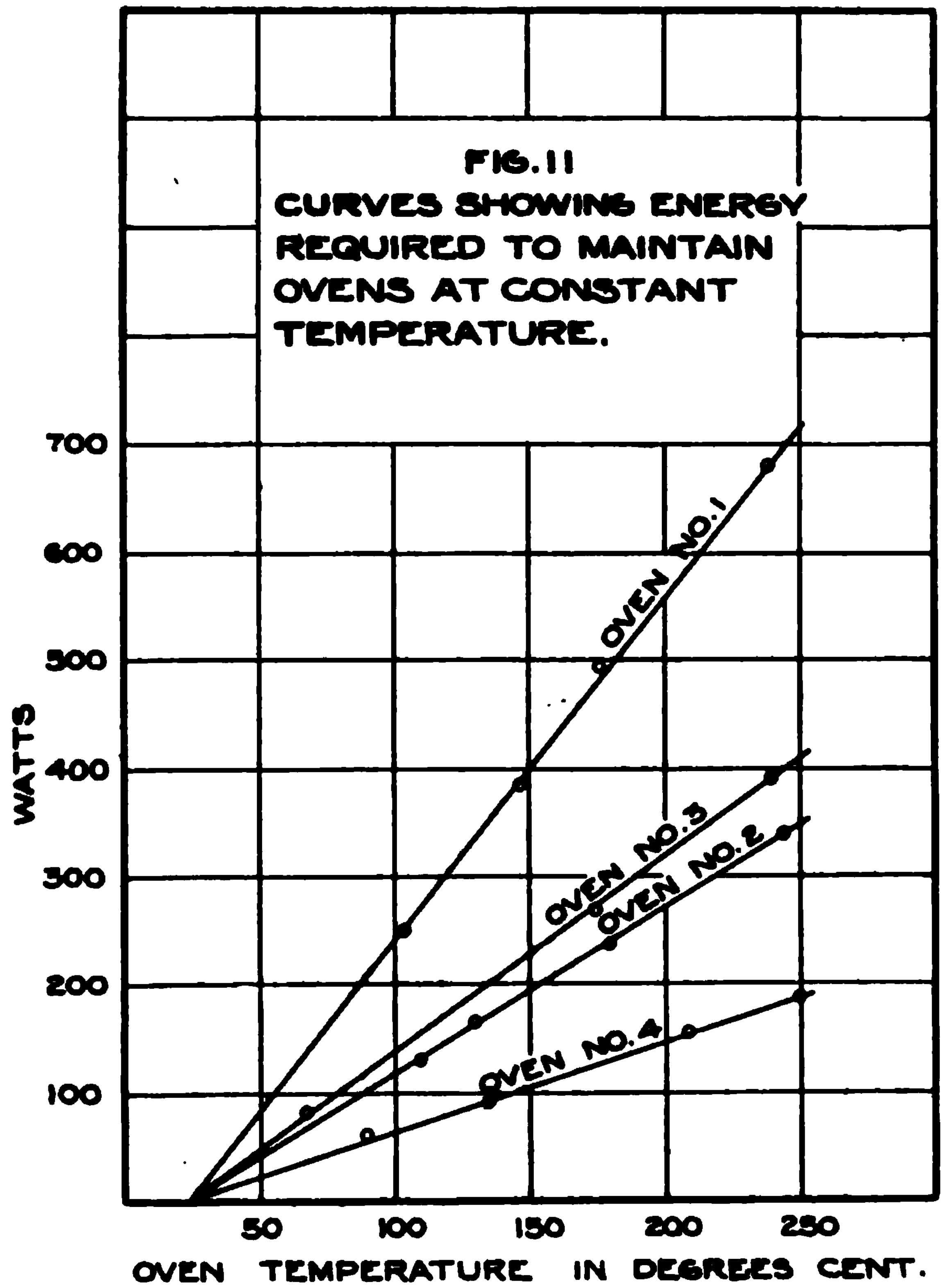


FIG. 11
CURVES SHOWING ENERGY REQUIRED TO MAINTAIN OVENS AT CONSTANT TEMPERATURE.

tinuously, it cools off in the interval during which it is idle. Before it can be again used the inside of the oven and the contained air must be heated up to a cooking temperature. This operation is called preheating. The amount of energy required to preheat an oven to the desired temperature depends upon the insulation of the oven, the dimensions, the thermal capacity of the inside, and the size of the heating coils. The amount of energy required to preheat the ovens tested was

obtained by taking simultaneous readings of the thermometer and the watt-hour meter. Fig. 12 shows the results obtained. It will be noticed that altho oven No. 4 was better insulated than Oven No. 2 it required more energy for the preheating. This was probably due to the greater heat capacity of the inside lining and the throat. The effect of too small a heating coil is shown by the curve for oven No. 3. For high temperatures the energy required for preheating this oven is alto-

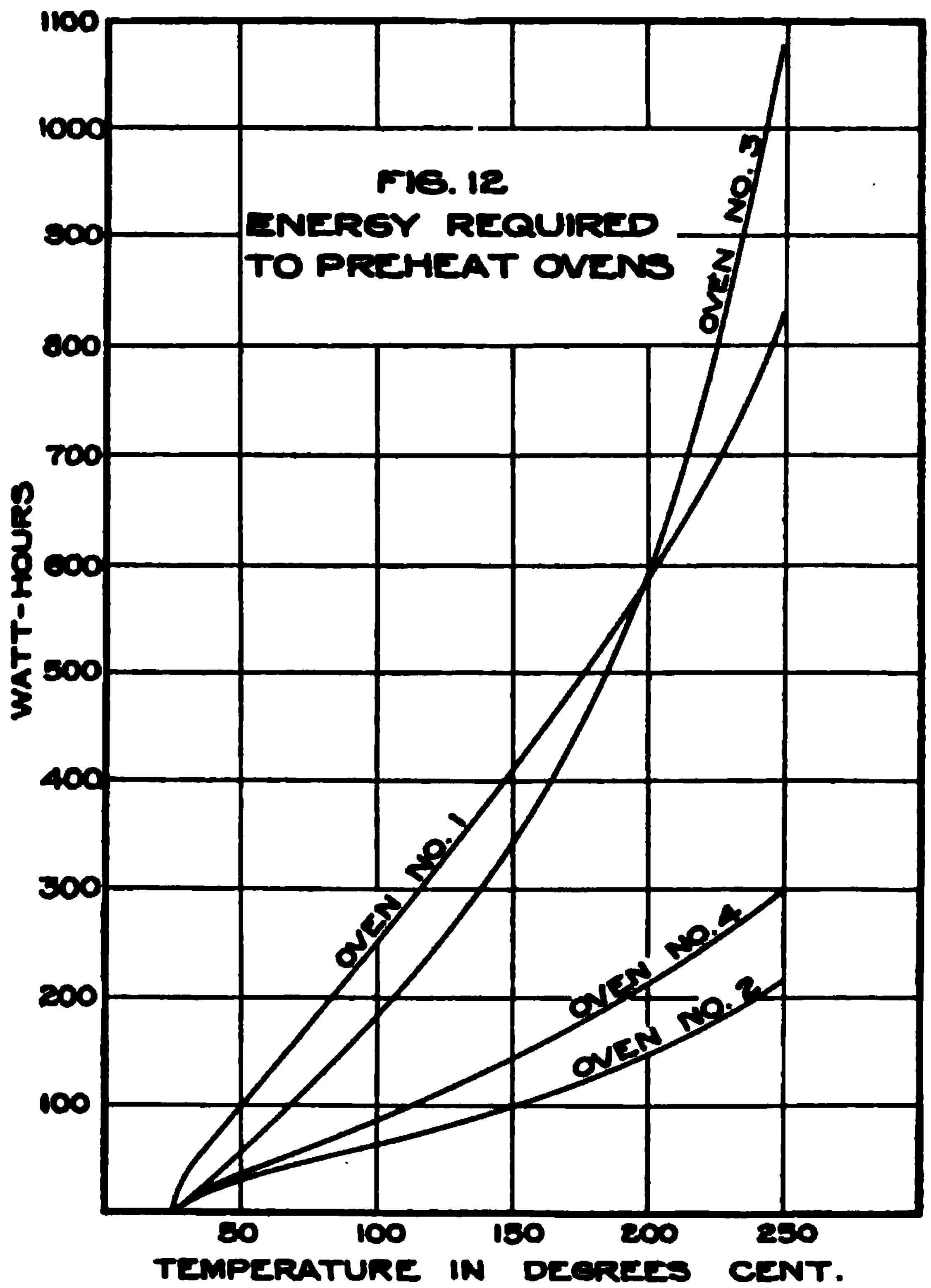


FIG. 12
ENERGY REQUIRED
TO PREHEAT OVENS

gether too large for the size of the oven. The fact that the heating coil is below the bottom of the oven also caused the oven to heat more slowly, the time required for it to reach the higher cooking temperatures being 2.5 hours for 250°C. (482°F.). In order that the energy required for preheating may be as small as possible the inner parts of the oven should have the least practical heat capacity and the heating coils should be large enough to bring the oven to the desired tem-

perature in a fairly short time. If the time required for the oven to reach the cooking temperature is excessive, not only is there a delay in the cooking operation but a larger amount of the energy is lost into the room by radiation and convection during the time of preheating.

Heat Loss When Oven Door Is Opened. In preparing food which cannot be placed in a cold oven and gradually heated, there is a loss of heat when the oven door is opened. The amount of this loss and the

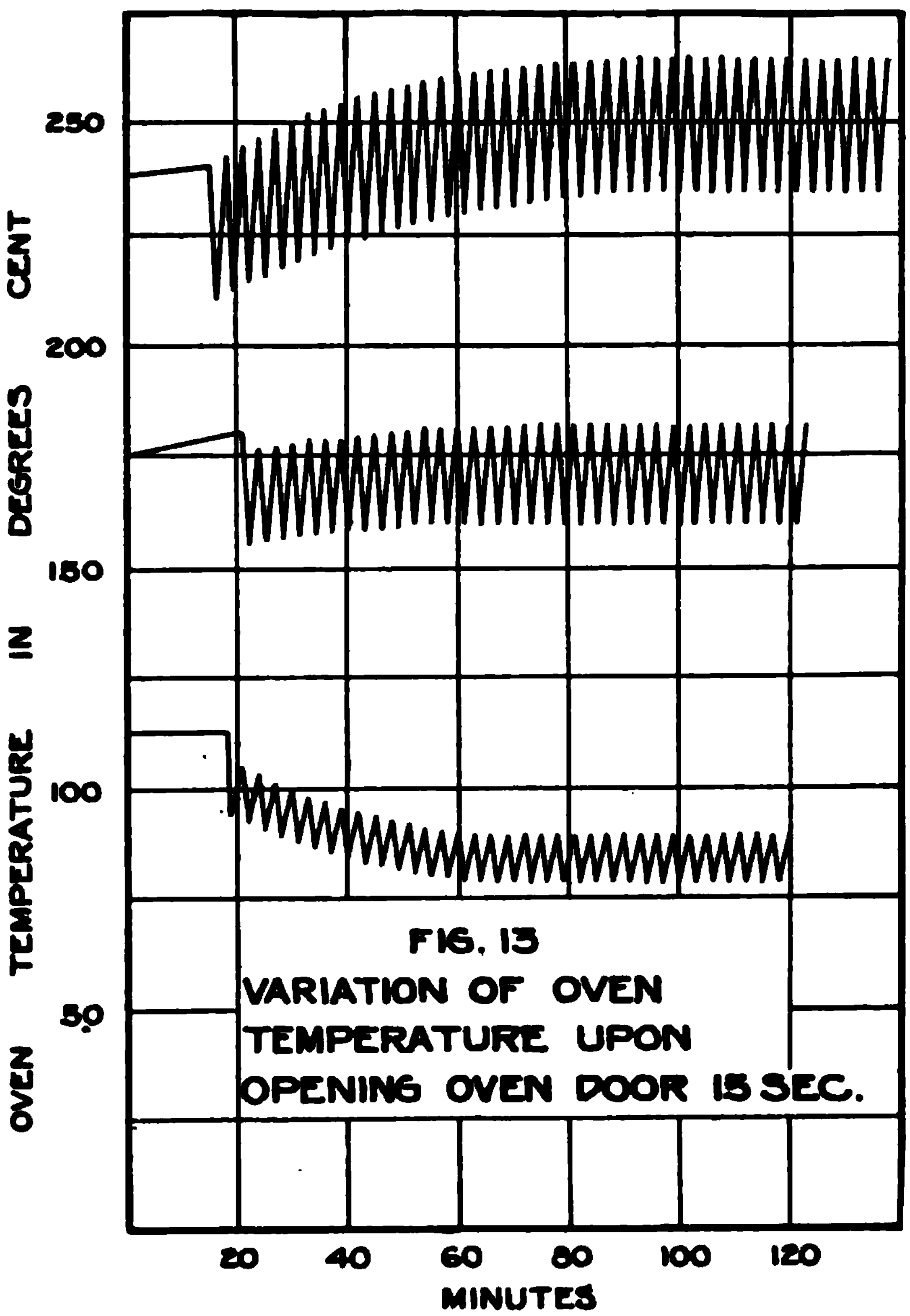
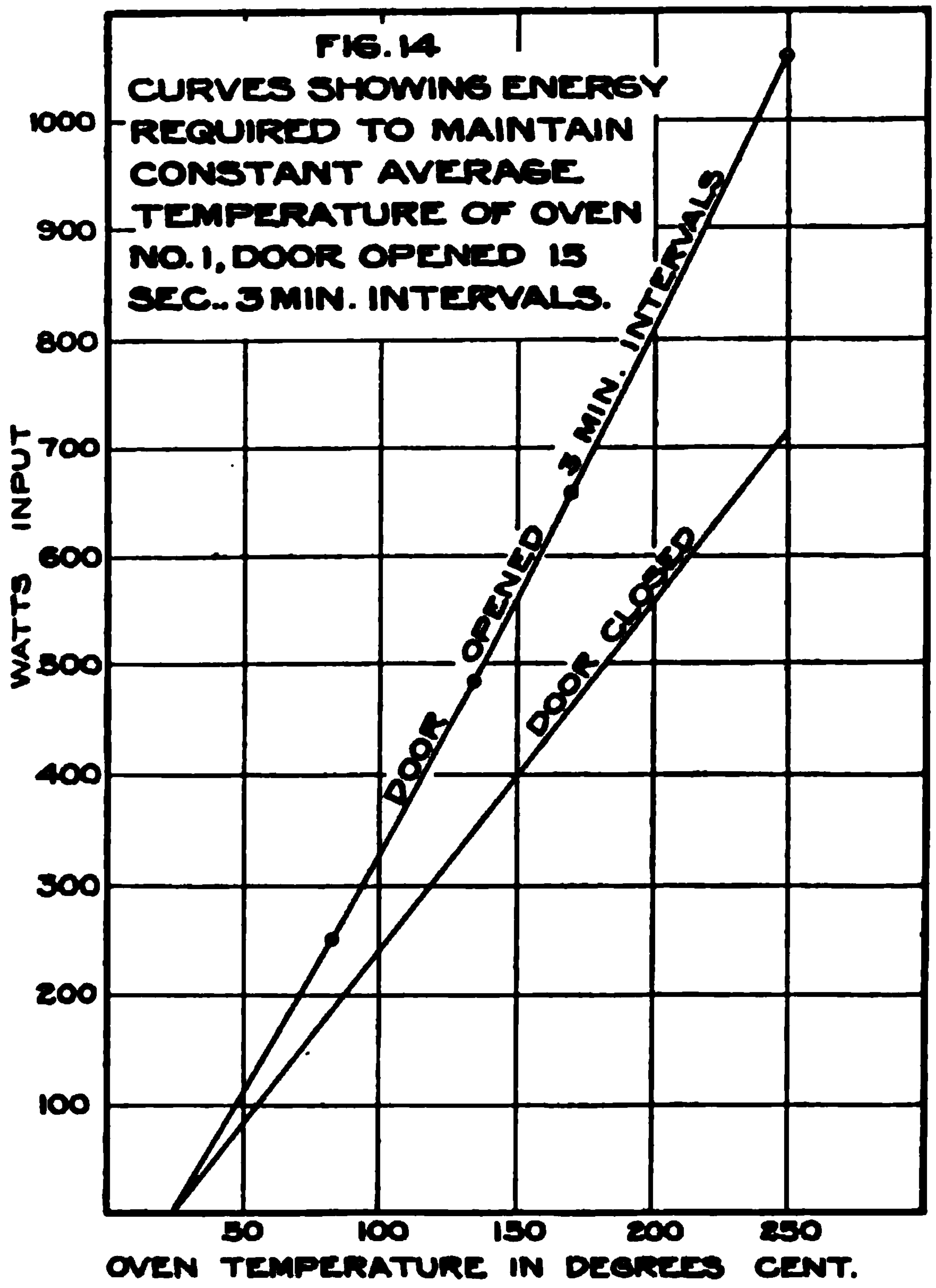


FIG. 13
VARIATION OF OVEN TEMPERATURE UPON OPENING OVEN DOOR 15 SEC.

fall of temperature in the oven were determined for oven No. 1 as follows: The energy input was measured by means of a wattmeter and was kept constant for each test. The temperature of the oven was obtained by means of the thermo-couple and recording galvanometer. The variation of the temperature of the oven when the door was opened for 15 seconds at three-minute intervals is shown in Fig. 13. The average temperature gradually changes and finally reaches a constant

value. A curve plotted for these average temperatures and the energy input is shown in Fig. 14. The difference between the ordinates of this curve and the similar curve obtained with the door closed evidently represents the energy lost by opening the door. From these values the energy lost each time the door is opened is readily calculated. Fig. 15 shows the watt-hours lost each time the door of oven



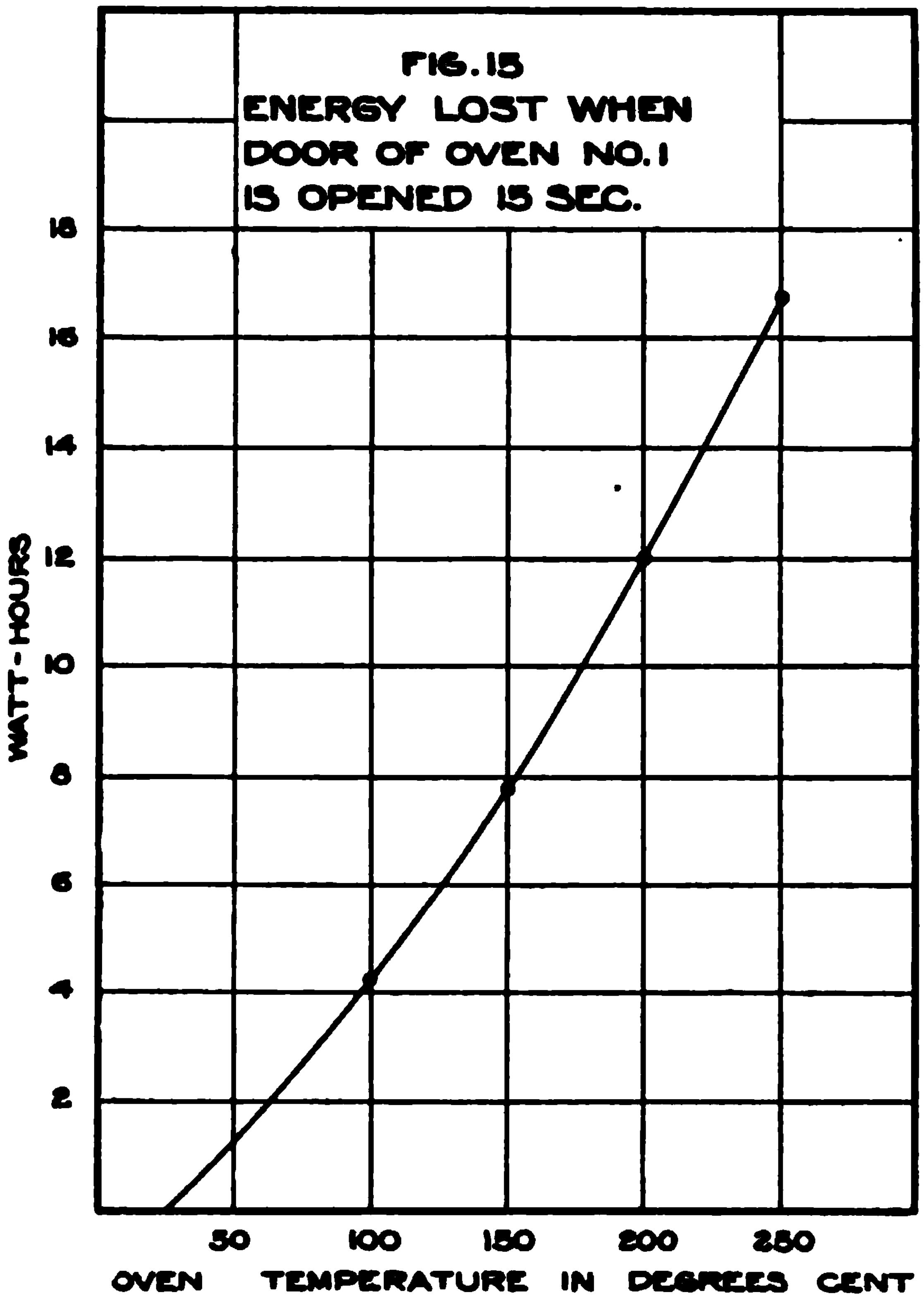
No. 1 is opened for 15 seconds. Fig. 16 shows the fall in temperature of the oven when the door is opened at different oven temperatures.

Efficiency. Of the energy input of an electric oven only the part which is absorbed by the food is used to advantage. The remainder goes to supply losses, such as radiation, convection, preheating, opening the oven door, and heating the utensil containing the food.

The ratio of the energy utilized in a piece of apparatus in doing useful work to the total energy input is said to be the efficiency of

that apparatus. Using this meaning, the efficiency of cooking apparatus is the ratio of the energy absorbed by the food to the total energy input of the fuel whether in the form of coal, gas, or electricity.

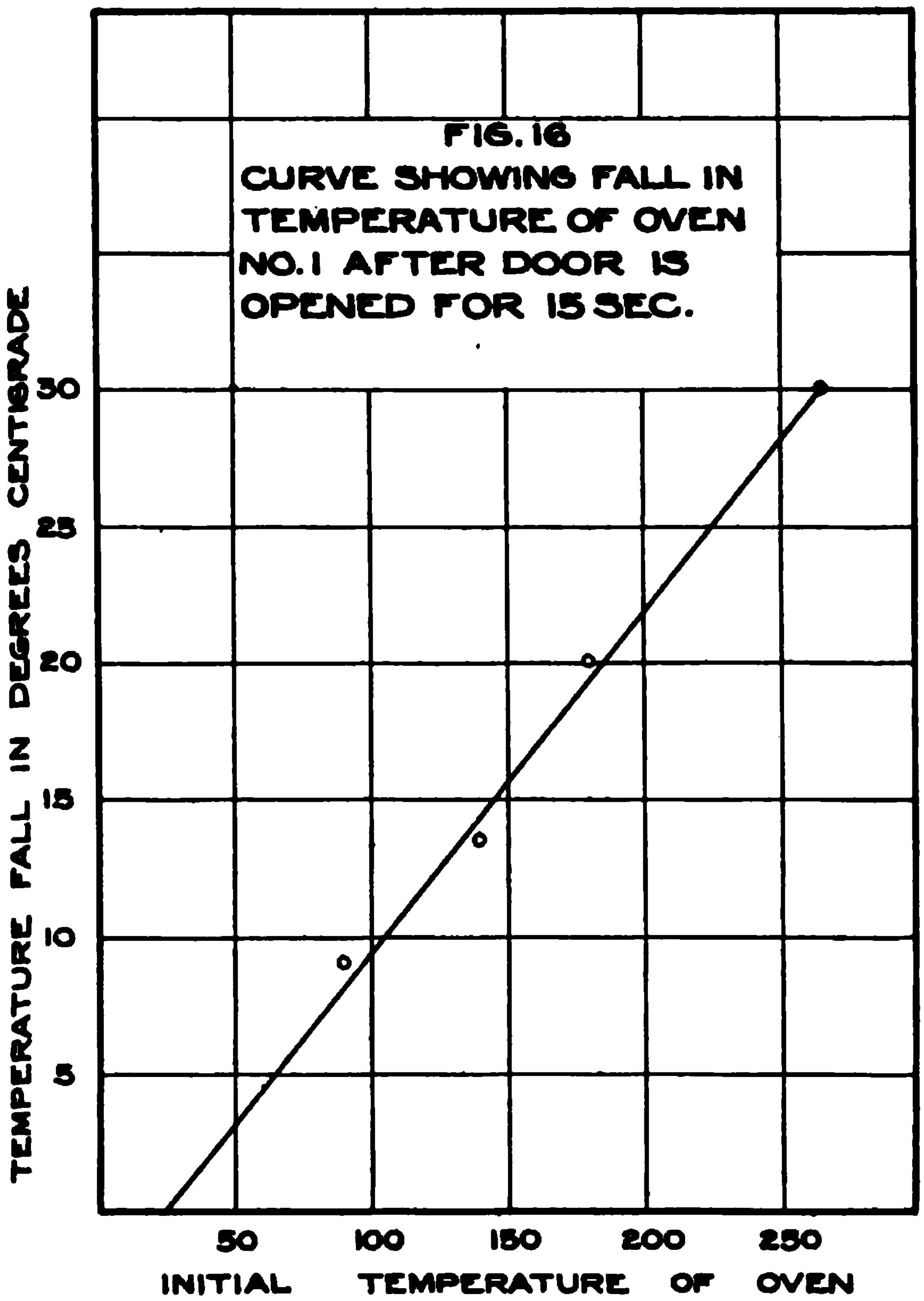
To get a useful expression for the efficiency of a cooking device is not as simple a problem as it may seem. Some investigators have adopted the method used to determine the efficiency of a steam boiler and firebox. They have heated a quantity of water, calculated the



number of heat units absorbed by the water, and taken as the efficiency of the stove or oven the ratio of the heat units absorbed by the water to the heat units supplied by the fuel. This does not take into account the fundamental difference in the purpose of the cooking apparatus and the steam boiler. The purpose of the steam boiler is to convey as many heat units from the fuel to the steam as may be possible. That is, likewise, the purpose in heating water for domestic uses, but it is not the object in view when cooking food.

As explained in a previous paragraph the object in cooking food is to improve its flavor or to increase its digestibility or both. These two factors are the criteria of a well-cooked food. Very often food which has absorbed the greatest number of heat units is the most badly cooked, and the method of cooking which utilizes the largest part of the energy input may give the poorest results.

As an example of why the steam boiler method of determining the efficiency of a cooking device is inadequate, let us suppose that a



cereal is to be cooked for two hours at 90°C. (194°F.). Only such an amount of water is added as will be absorbed by the cereal during the cooking. It is placed in a well-insulated oven, heated rapidly from 20° to 90°C. (68° to 194°F.), and then kept at that temperature for two hours by supplying just enough energy to make up for radiation losses. During the first part of the process energy will be absorbed by the food as it is heated from the room temperature to the

cooking temperature. The efficiency will lie somewhere between 20 per cent and 70 per cent depending on the characteristics of the oven, its initial temperature and the size and shape of the vessel used. During the last part of the cooking process very little energy will be used by the heating coil but practically no energy will be absorbed by the food, so that the efficiency will be zero.

Another oven requiring less energy for preheating and not being so well insulated would show a better efficiency during the first fifteen minutes when the food is being heated up, but during the last two hours would require more energy than the first oven to make up for the greater radiation losses. The total energy supplied might be greater for the second oven and yet the efficiency as calculated from the heating up part of the cooking process, or as determined by heating a known quantity of water, would be less.

Evidently, the final consideration in comparing the efficiency of two ovens is this,—which one will cook a given article of food in the best manner with the expenditure of the least amount of fuel? This suggests another method of specifying the operating efficiencies of cooking apparatus: to determine the amount of energy required to cook a standard article of food under standard conditions, specifying the quality of the food, the quantity, and the time and temperature of cooking. This method might prove satisfactory if the standard conditions could be determined so as to be reliable and be typical of average cooking processes. There would be a difficulty, however, in assuming any one article of food as a standard. The conditions of cooking vary to such an extent that a particular oven might be more economical for cooking one kind of food and less so for another kind. For instance, biscuits require a short time of cooking at a high temperature, ten to fifteen minutes at 200° to 220°C. (392° to 428°F.) while cereals and vegetables are best cooked for several hours at a temperature somewhat below boiling.

Another method of indicating the efficiency of electric ovens would be to specify the energy required to supply the losses. The loss due to opening the oven door will be practically the same for all ovens of the same size so that the principal losses will be those due to radiation, convection and preheating. Evidently, when a particular article of food is cooked under the same conditions of time and temperature in various ovens, the part of the energy input absorbed by the food will be practically the same while the part of the energy input not absorbed by the food, or the losses, will depend upon the characteristics of the oven. If the energy required to heat various ovens to any given temperature and the energy required to maintain the oven temperatures at the desired value are known, then the cost of operation of any of the ovens can easily be determined for any kind of cooking; providing, of course, that the time and temperature used for that cooking are known.

For the purpose of comparison with the results of other investigators the apparent efficiency of three electric ovens and a gas oven were determined by heating a known quantity of water. Four thousand grams of water were used in each test. The water was placed in an aluminum dish weighing 451 grams. This dish was chosen as it was the one used in some meat tests to be described later. The dish was used without a cover. The water was weighed carefully before and after each test. The temperature of the water was read just before it was placed in the oven and just after it was removed. The energy used in evaporation and the energy absorbed by the dish were included in the total energy absorbed. One set of tests was made by placing the water in the oven when the temperature of the oven was the same as that of the room and then turning the heating units on full. Another set of tests was made by placing the water in the oven when the temperature of the oven was 150°C. (302°F.) turning the heat on full until the temperature had returned to that value and then keeping the oven temperature constant for the remainder of the test. Tests were also made with the heating units on top of oven No. 1 and the top burners of the gas stove. The results of the tests are given in Table II.

The high efficiency of the top heating coils is due to the good heat connection between the heating units and the dish of water. On top of the stove there is approximately one-tenth of an inch space between the red hot coils and the bottom of the dish while in the oven the coils and the dish are separated several inches with a baffle between. Because of the poor heat connection between the coils of the oven and the dish the heat is conducted very slowly from the coils to the water.

The results of the tests indicate that water could not be heated as efficiently by placing it in the oven as by heating it on top of the stove. It does not follow, however, that all cooking can be done more economically on top of the stove than in the oven. The contrary may be true in many cases; for instance, it would be cheaper to prepare a pot-roast in oven No. 2 or No. 4 than it would be to prepare it on top of the stove on the heating coil tested. This is because the purpose of cooking the pot-roast is not to put the greatest amount of heat into it with the minimum cost, but the purpose is to keep the roast at a temperature of 80°C. (176°F.) for three or four hours until it is satisfactorily cooked. Articles of food like vegetables or a pot-roast which are prepared in water could be cooked still more economically by removing the baffle from the oven and placing the dish directly on the heating element. Advantage is then obtained of the good heat contact between the heating coil and the dish of food and the smaller radiation losses of the oven. The best results for this kind of cooking in which there is enough water to prevent scorching would be obtained in an insulated oven but little larger than the dish containing the food.

Table II.

Temperature of ovens at beginning of test 25° C. (77° F.).

Apparatus	Calories absorbed	Energy used	Calories input	Efficiency percent
No. 1. oven	60.4	571 watt-hr.	492	12.3
No. 2 oven	138.9	452 watt-hr.	389	35.7
No. 4 oven	205.5	525 watt-hr.	452	45.5
Gas oven	106.6	11 cu. ft.	1940	5.5
Temperature of ovens thruout test 150° C. (302° F.).				
No. 1 oven	71.4	316 watt-hr.	272	26.0
No. 2 oven	109.0	281 watt-hr.	242	45.0
No. 4 oven	108.5	198 watt-hr.	170	64.0
Gas oven	119.0	6.2 cu. ft.	1100	10.8
Gas burner	191.0	2.75 cu. ft.	485	39.4
Top burner No. 1 oven	243.0	457 watt-hr.	393	61.8

MEAT COOKERY

Meat may be cooked by any of the methods in common use,—roasting, baking, frying, broiling, stewing, or boiling. Little has been known concerning the scientific principles of cooking meat until recently. Since there has been no uniformity in the practices and processes of cooking, the terms used vary widely in their meaning. Roasting,—which was formerly applied to cooking over red hot coals,—is now used synonymously with baking or cooking in an oven by means of a dry heat. Stewing and boiling have never been clearly defined. Both apply to the cooking of meat when immersed in water. The present tendency in scientific literature is to use the term boiling when meat is cooked in water at any temperature and to specify the exact temperature used. Broiling and frying will not be discussed in this paper, since it is impractical to utilize the advantages of an insulated electric oven for preparing meat by either method.

There is a wide diversity of taste in regard to the proper degree of cooking of a meat roast. Some people prefer that the meat should be heated only enough to slightly change the color of the interior, while others prefer the meat cooked until every trace of the pink color has disappeared. This difference of taste causes a corresponding variation in the meaning of the terms used to describe the degree to which meat shall be cooked. The meat which one would call rare is, to another, medium rare, and, at times, meat that is actually raw is served as rare.

In this paper the terms rare, medium rare, and well-done are used to indicate the same degree of cooking as defined by Miss E. C. Sprague.[1] The definitions are as follows:

"**Rare or Under-done Meat.** In the center of a rare roast the dull bluish-red characteristic of the raw meat has changed into the bright rose-red of the rare meat. This shades into a lighter pink toward the outer portions and changes into a dark gray in the layer immediately underlying the outer browned crust. The ideal standard for rare meat requires that the larger portion of the roast shall have been heated only enough to effect this first change to rose-red, so that the outer brown crust and the intermediate gray layer shall be as thin as possible. Under these conditions there will be a liberal amount of bright red juice.

"**Well-done Meat.** If the cooking is continued for a sufficient length of time, instead of being distended the meat shrinks noticeably. The whole interior is found to have become brownish-gray in color and the juice is scanty and either colorless or slightly yellow. Meat cooked to this degree is said to be well-done.

"**Medium Rare Meat.** A condition between these two extremes is indicated by the term medium rare. In this case sufficient heat has been applied to change the color of the center to a light pink. The gray layer underlying the crust has, therefore, extended considerably toward the center. The free juice is smaller in quantity and lighter in color than in the rare meat."

The experiments of Grindley and Sprague have demonstrated that beef can be satisfactorily roasted at an oven temperature anywhere between 100° and 200°C. (212° and 392°F.). A beef roast prepared at any temperature within this interval was found to be well browned and attractive looking. No difference was discernible in the tenderness of duplicate roasts cooked at the extremes of temperature. In their opinion the flavor and juiciness of the meat was slightly better at the lower temperatures, whereas at the higher temperature the drippings were better flavored and larger in quantity.

Since a roast of beef can be properly prepared at any temperature between 100° and 200°C. (212° and 392°F.) the most satisfactory temperature within this interval can be determined only by the consideration of other factors, of which the time of cooking and the cost of cooking are the most important. In order to determine this most economical temperature for roasting a rolled rib roast, a series of experiments were performed.

Twenty-two roasts consisting of the third and fourth standing rib cuts, as near alike in size and quality as possible, were obtained from a local market. The meat was freed from bone, tightly rolled, and

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1. University Studies, Univ. of Ill., Vol. 2, No. 4, p. 4.

secured with wooden skewers. Samples were roasted at 100°, 120,° 140°, 160°, and 180°C. (212°, 248°, 284°, 320° and 356°F.) The time required for the cooking and the amount of energy used at each temperature was measured, from which the most economical temperature for cooking a rolled roast was determined.

In order to get uniform results in the degree of cooking of the meat it was necessary to decide on a rather exact method of determining when the meat was sufficiently cooked. As mentioned before, the aim in cooking meat is not to increase its digestibility but to improve its flavor and appearance. This is accomplished by decomposing the red coloring matter called oxyhaemoglobin, which removes the raw appearance of the meat. The inside of the roast should be heated sufficiently to accomplish this without overcoagulating the proteids or removing from the meat those substances which tend to become soluble or volatile upon the application of heat.

Milroy's experiments [1] show that approximately 50 per cent of the protein of fresh beef was coagulated at 50°C. (122°F.), 70 per cent at 60°C. (140°F.), 90 per cent at 70°C. (158°F.) and 100 per cent at 80°C. (176°F.). At about 75°C. (167°F.) the oxyhaemoglobin undergoes a decomposition which probably marks the disappearance of the last trace of red in the meat. These results would indicate that the inside of the meat ought to reach a temperature between 50° and 80°C. (122° and 176°F.) to be properly cooked, the exact temperature depending upon the degree of cooking which people prefer.

Grindley and Sprague [2] found that if the inner temperature of a roast is between 55° and 65°C. (131° and 149°F.) the meat will be rare, if it is between 65° and 70°C. (149° and 158°F.) it will be medium rare, and if between 70° and 80°C. (158° and 176°F.) it will be well done. In order to secure as much uniformity as possible in the results, a definite temperature rather than a range of temperature was taken as an indication when the meat was sufficiently cooked. Fifty-five degrees C. (131°F.) was used for rare, 65°C. (149°F.) for medium rare, and 75°C. (167°F.) for well done which conforms to the usage of other experimenters. It was not always possible, however, to obtain the exact inner temperature to a degree, because if the roast is taken out of the oven when the inner portion of the meat is at some particular temperature, this temperature will first increase several degrees before it begins to decrease. This increase of temperature after the roast is removed from the oven depends upon the temperature of the oven in which the meat is cooked, being greater for a high oven temperature. The following temperatures of the roasts when removed from the oven were found to give the desired results:

1. Archiv. f. Hyg., 1895, XXV., p. 154.
2. Univ. of Ill. Bul., Vol. II, p. 290.

Table III.

Oven Temperature. Degrees		Inner temperature of the meat when removed from the oven. Degrees					
		Rare		Medium Rare		Well Done	
Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
100	212	53	127.4	63	145.4	75	167.0
120	248	51	123.8	61	141.8	73	163.4
140	284	49	120.2	59	138.2	72	161.6
160	320	46	114.8	57	134.6	71	159.8
180	356	43	109.4	55	131.0	70	158.0
		Highest inner temperature of the roast after removing from the oven.					
		55	131.0	65	149.0	75	167.0

A copper-constantan thermo-couple, as described in a preceding chapter, was used to measure the temperature inside the roasts. The thermo-couple was connected to the recording galvanometer which gave a continuous record of the temperature at the center of the roast. Fig. 17 shows some of these curves reproduced on rectangular co-ordinates. Altho these curves do not have a direct bearing on the problem in hand, they are given here as they may be of some interest in other cooking investigations.

The authorities on meat cooking recommend that a roast be cooked for the first ten or fifteen minutes at an oven temperature of 250°C. (482°F.) so as to sear the outside of the meat. The theory is that the coagulation of the outer surface of the meat will act as a seal to keep in the meat juices. A consideration of the heating curves of the electric ovens, discussed in the first part of this paper, shows that to heat an oven up to 250°C. and keep it there for fifteen minutes will increase the cost of electricity for roasting the meat about .50 per cent. In order to reduce this extra cost of energy another method was tried which proved very successful. Instead of searing the meat in an oven at a high temperature it was seared on top of the stove or rather by placing it in an aluminum dish over an 880-watt heating coil. The current was turned on for three minutes to get the dish quite hot. The meat was then placed in the hot dish and seared for ten minutes, being turned frequently so as to sear all sides.

After searing, an incision was made in the roast with a sharp narrow-bladed knife, and the thermo-couple was inserted as near as possible in the center of the large muscle of the roast. The roast was then placed in the oven at the required temperature. Placing the roast in the oven lowered the temperature from 10° to 20°C. (18° to 36°F.). The full current of the oven was then turned on and in two to five minutes the temperature of the oven had again reached the

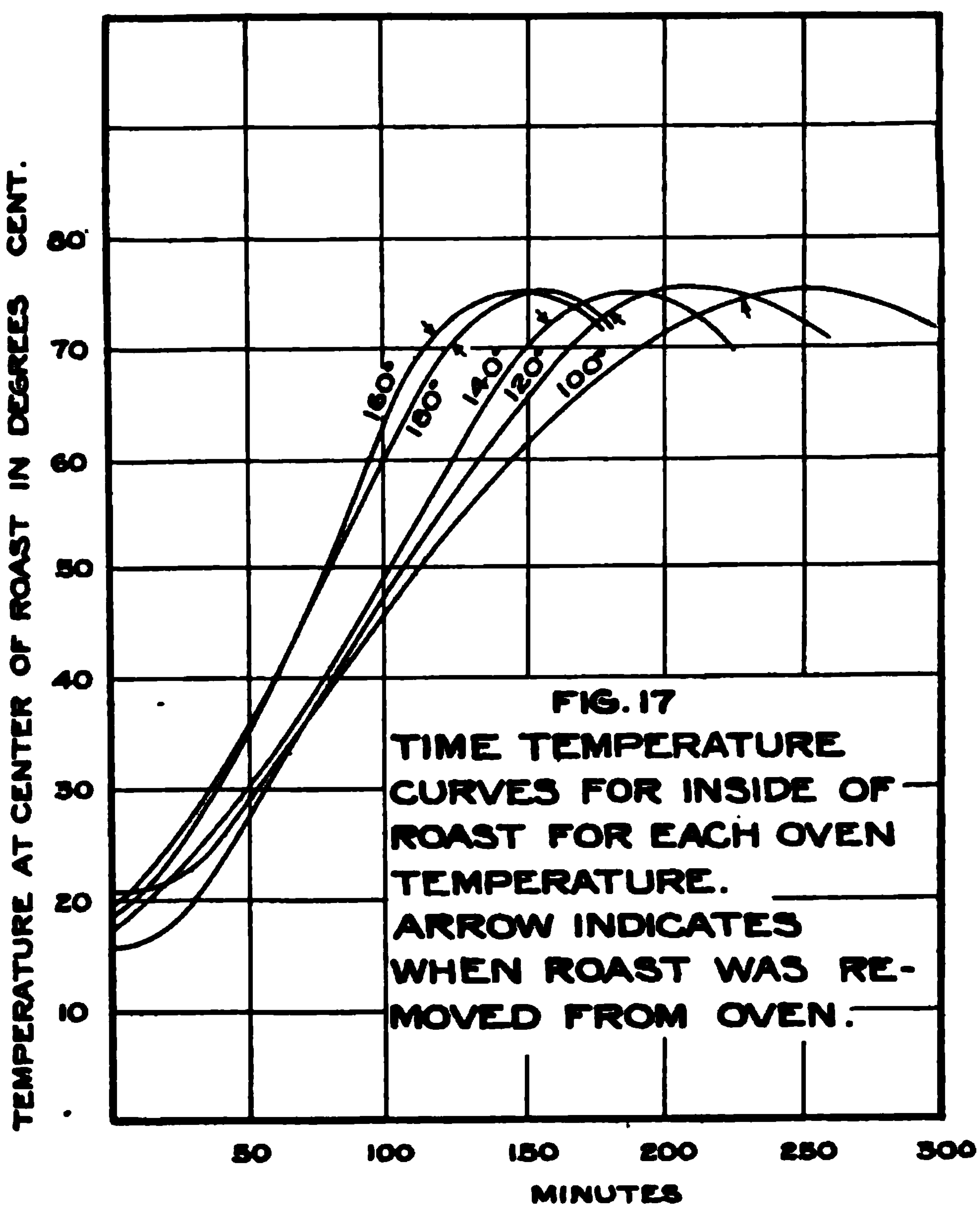


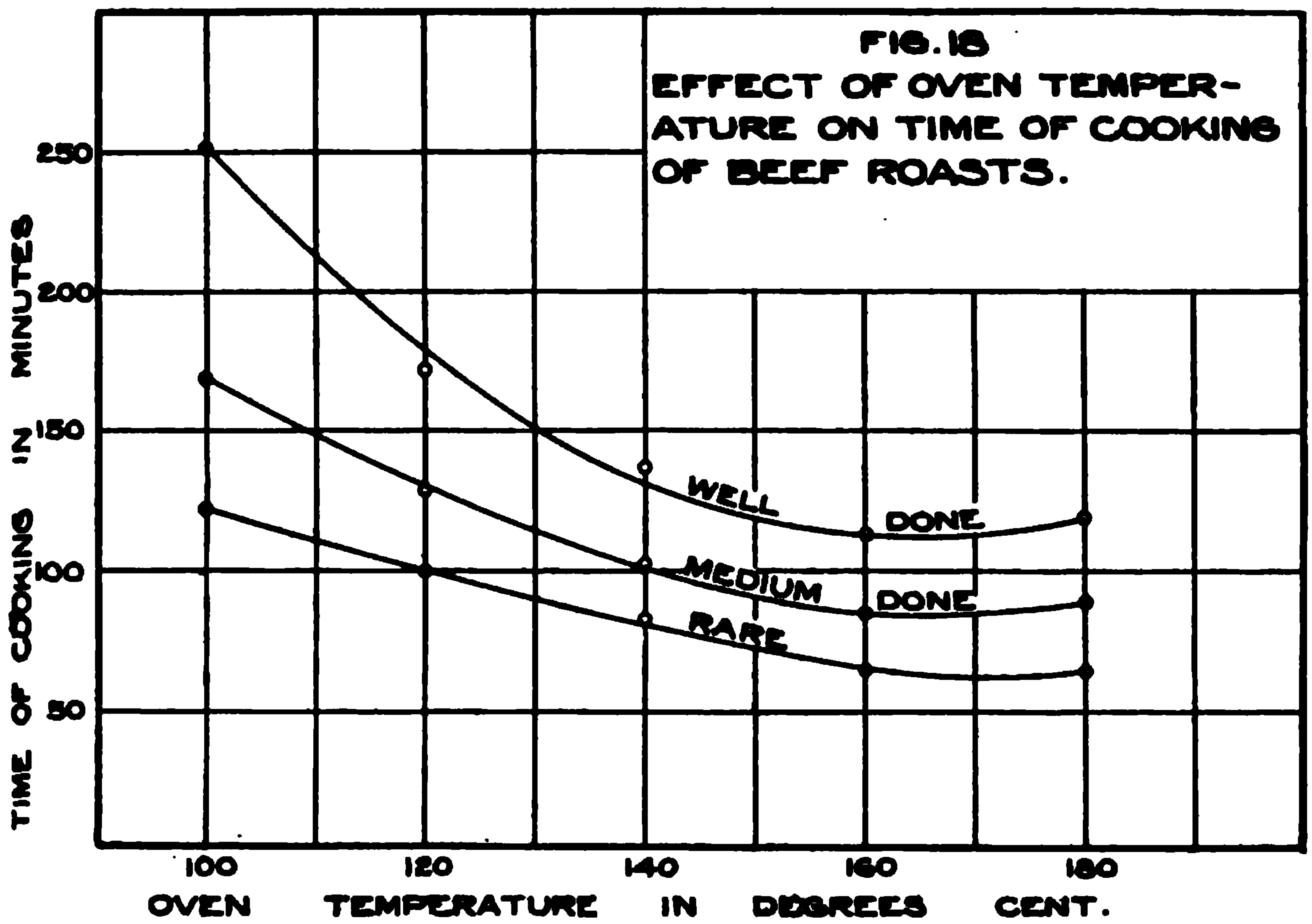
FIG. 17
TIME TEMPERATURE CURVES FOR INSIDE OF ROAST FOR EACH OVEN TEMPERATURE.
ARROW INDICATES WHEN ROAST WAS REMOVED FROM OVEN.

required value. During the remainder of the test the current in the oven was varied by means of a rheostat so that the temperature remained constant within 2°C. (3.6°F.) of the desired value.

When the temperature inside the roast indicated the meat to be cooked rare, the time and watt-hour readings were recorded. This was also dône for medium rare and well done. As soon as the inside temperature indicated the meat to be well done, the roast was taken

out of the oven and left on a shelf in front of the oven, the leads of the thermo-couple being long enough so that it could still be left inside the meat. The meat was allowed to stand until after the temperature had reached its maximum value. It was then weighed and put on ice until the next day when it was cut into and examined.

Table IV. gives the time of cooking of the roasts for rare, medium rare, and well done. The average values lie close to smooth curves as



shown in Fig. 18. It will be noticed that at an oven temperature of 160°C. (320°F.) the roasts are cooked in a shorter length of time than at 180°C. (356°F.). This is probably due to the fact that the slightly charred surface of the meat is a poorer conductor of heat. For the well-done roasts the time of cooking increases rather rapidly as the temperature decreases. This is not a disadvantage, however, if the proper temperature can be obtained automatically without the attention of the cook.

Table IV.

Temp. of oven		Time of cooking of meat roasts in minutes			
Cent.	Fahr.	Rare			Average
100	212	121	122	120	121
120	248	107	89	97	98
140	284	99	76	71	82
160	320	53	71	67	64
180	356	80	58	53	63
		Medium Rare			
100	212	162	176	170	169
120	248	139	114	124	126
140	284	111	89	106	102
160	320	75	91	86	84
180	356	105	82	75	88
		Well Done			
100	212	241	260	248	250
120	248	177	165	172	171
140	284	151	124	132	136
160	320	164	120	113	112
180	356	135	105	113	118

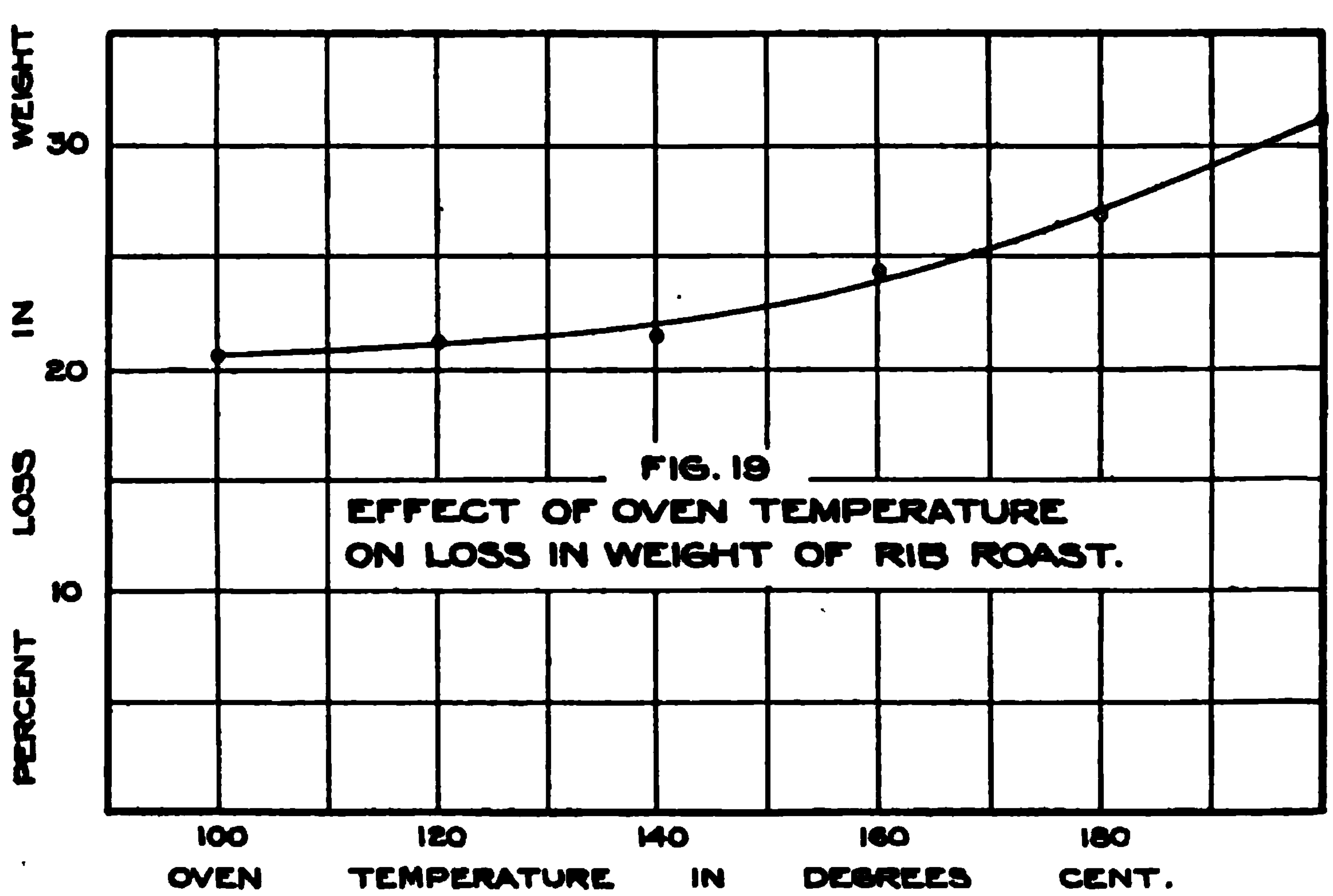


FIG. 19
EFFECT OF OVEN TEMPERATURE ON LOSS IN WEIGHT OF RIB ROAST.

Table V gives the weights of the roasts before and after cooking and the per cent loss in weight due to the cooking. The average values of the per cent loss in weight of the roasts in cooking are plotted in Fig. 19. It will be noticed that the per cent loss in weight of the roasts increases with the temperature. The curve shows that in cooking a well-done roast so far as losses are concerned, meat is best when cooked between 100° and 120°C. (212° and 248°F.) or possibly lower.

Table V.

Temp. of oven		Weight before cooking Grams	Weight after cooking Grams	Loss in weight	Per cent loss in weight	Average per cent loss
Cent.	Fahr.					
100	212	1904	1502	402	21.1	
		1600	1288	312	19.5	
		1760	1392	368	20.9	20.5
120	248	1580	1270	310	19.6	
		1782	1380	402	22.6	
		1824	1434	390	21.4	21.2
140	284	1700	1352	348	20.5	
		1900	1492	408	21.5	
		1820	1414	406	22.3	21.4
160	320	1554	1160	394	25.3	
		1612	1237	375	23.2	
		1566	1182	384	24.5	24.3
180	356	1628	1220	408	25.1	
		1832	1335	497	27.1	
		1814	1300	514	28.3	26.8
200	392	1805	1244	561	31.0	31.0

As the proper facilities were not available, no attempt was made to analyze the drippings obtained at the various temperatures to determine the proportion of water, protein, and fat. The appearance of the drippings, however, would indicate that there is a larger proportion of fat in the drippings obtained at the high oven temperatures than at the low temperatures.

The other important factor which determines the best roasting temperature is the cost of the electricity used. As an aid to clearness in determining the most economical roasting temperature the total

energy used in cooking the meat will be divided into several components and each will be discussed separately.

As mentioned before the roasts were first seared over an open heating coil. This operation required 880 watts for 13 minutes or 190 watt-hr. and was the same for all the roasts.

Part of the total energy was used in heating the oven from room temperature to the temperature required for the cooking. This was done before the roast was put in the oven and is commonly known as preheating. The amount of energy required for this purpose, as shown in a preceding paragraph, depends upon the construction of the oven and the size of the heating coil. The curves of Fig. 12 show the energy required for the ovens tested.

If food is placed in an oven after the oven is heated to a certain temperature, the temperature will decrease, due partly to the heat lost by opening the door and partly to the heat absorbed by the cold utensil and food. To bring the temperature of the oven up to its former value additional energy will have to be supplied. The term afterheating will be used in this paper to distinguish this heating of the oven after food is inserted from the heating of the oven before the food is placed in it.

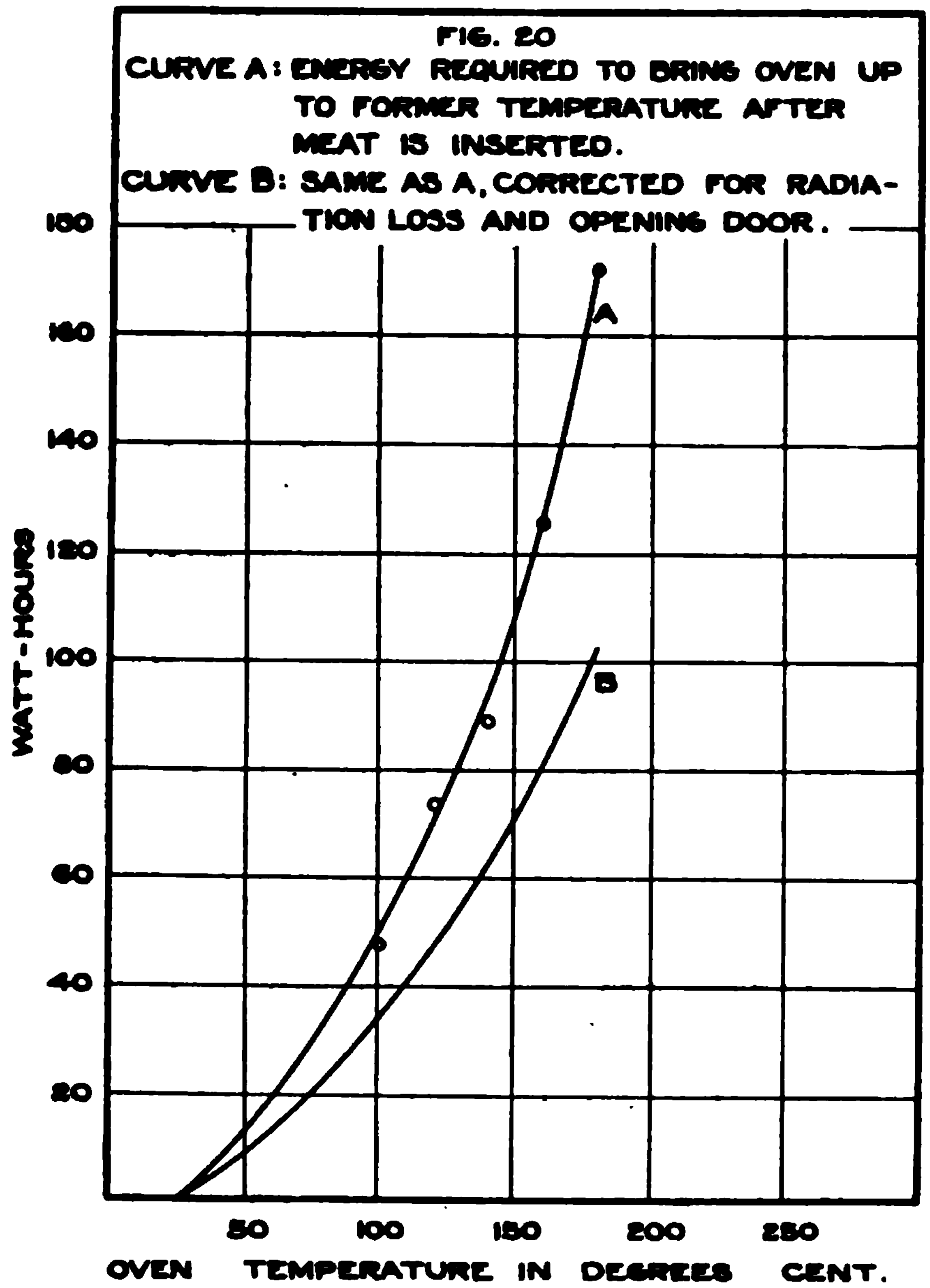
In the meat experiments the energy used in afterheating was determined. As soon as the meat was placed in the oven the current was turned on full until the temperature of the oven had increased to its original value. The reading of the watt-hour meter was then taken. The watt-hours thus determined are given in column 3 of Table VI for the various oven temperatures.

Table VI.

Oven temperature		Watt-hours required to bring oven temp. to former value after opening the door.	Watts required to maintain the oven and roast at constant temperature.
Cent.	Fahr.		
100	212	44	249
120	248	67	321
140	284	75	395
160	320	114	485
180	356	156	586

The variation of this energy with the oven temperature is shown by curve A in Fig. 20. The time required for the oven temperature to attain its former value after the roast was inserted varied from two to five minutes. During this time part of the energy supplied was

lost by conduction thru the insulation and around the throat as explained in a preceding paragraph. As this heat loss thru the walls of the oven is known for a particular temperature, the energy measured by the watt-hour meter (curve A Fig. 20) can be corrected by subtracting the energy lost thru the walls during the time required for the afterheating. Curve B Fig. 20 shows these corrected values. The

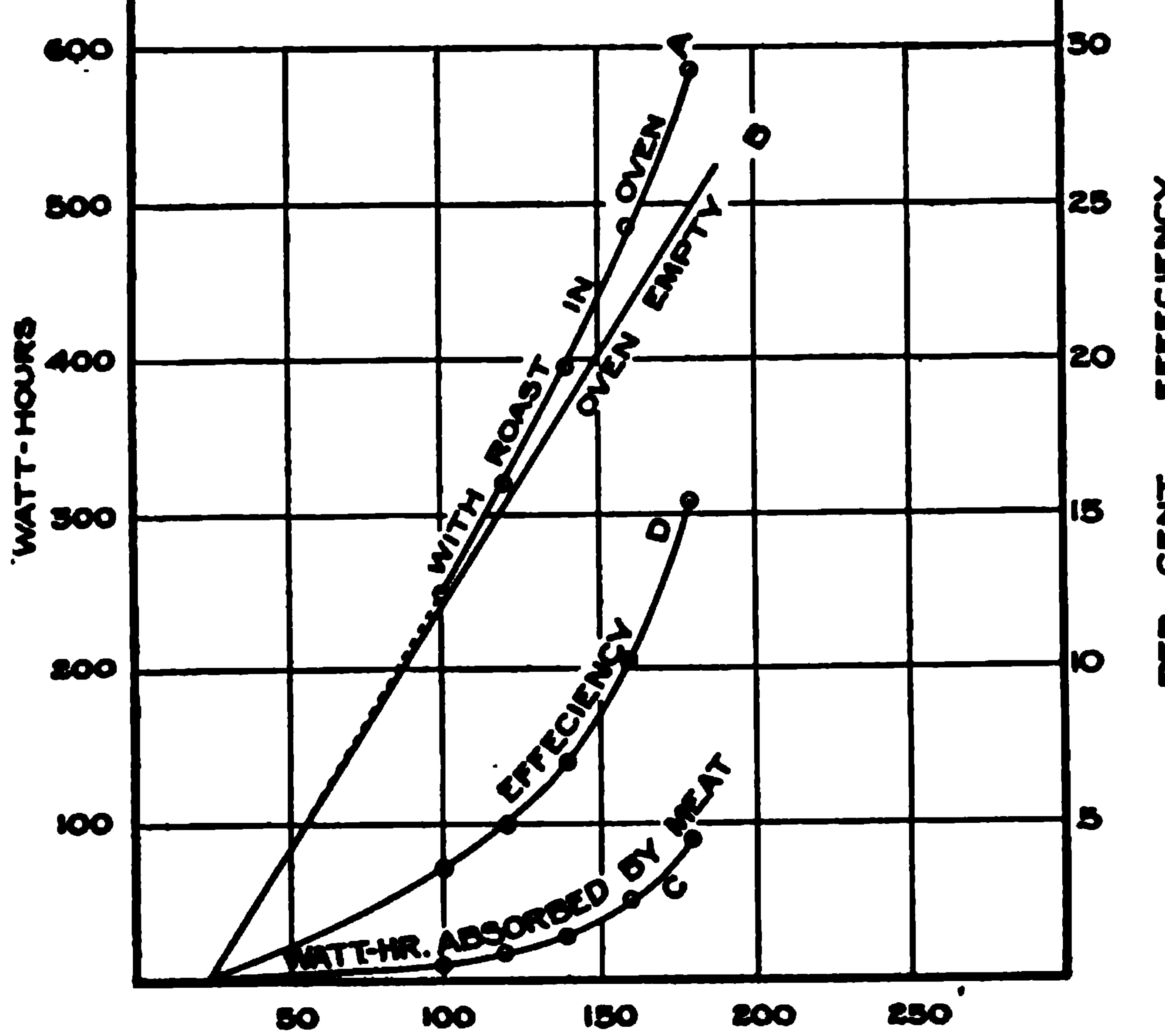


ordinates of this curve are a measure of the energy used in afterheating at the various oven temperatures.

After the temperature of the oven has attained the desired value the energy supplied to maintain this temperature is practically constant. Since the cooking of a roast consists in raising its temperature to 60°C. (140°F.) or above, there is a constant supply of heat energy to the meat. Part of this is used in increasing the internal temperature of the meat and part is used in vaporizing the water and other

volatile matter of the meat. Column 4 of Table VI gives the watts required to maintain the oven and roast at a constant temperature. Curve A Fig. 21 shows these values of watts plotted against oven temperature as abscissas. For the sake of comparison a similar curve for the empty oven is here repeated. The difference between these two curves is the energy absorbed by the meat either in increasing its temperature or vaporizing its moisture.

FIG. 21
ENERGY REQUIRED TO MAINTAIN OVEN AT CONSTANT TEMPERATURE WITH ROAST IN OVEN; AND EMPTY.



Consideration of these curves leads to a method of determining the ratio of the heat units absorbed by the food to the total heat units supplied. Since the ordinates of curve B represent the energy required to maintain the oven at a constant temperature when empty and the ordinates of curve A represent the energy required to maintain the oven at a constant temperature after the roast is placed therein; the difference between the two may be taken as a measure of the

energy actually absorbed by the food. In other words the difference between the ordinates represents the energy output of the oven. Therefore, for any oven temperature the ordinate of curve A minus the ordinate of curve B divided by the ordinate of curve A would equal the efficiency of the oven when roasting beef. Curve D of Fig. 21 gives the values of the efficiency obtained by this method. Even if

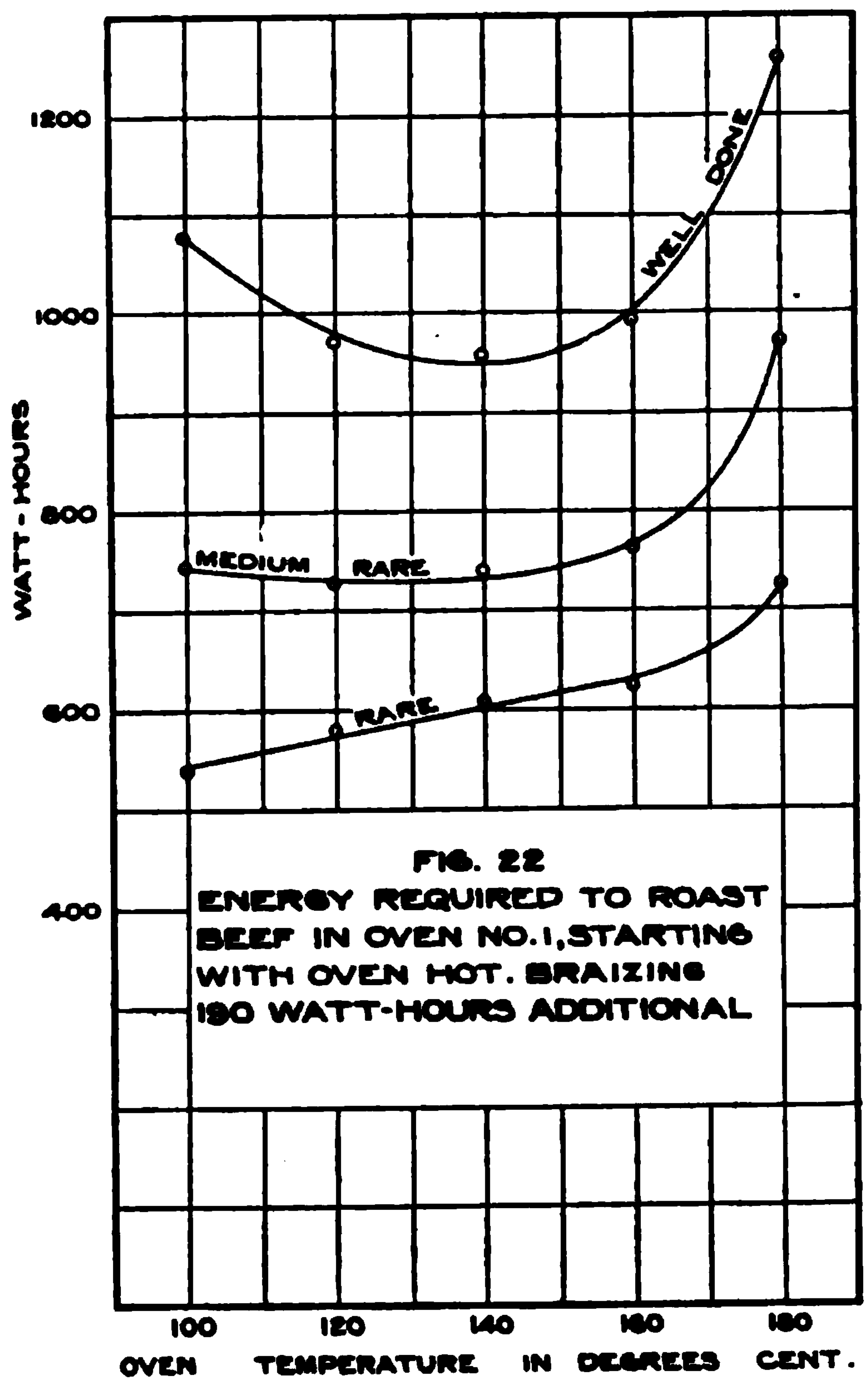
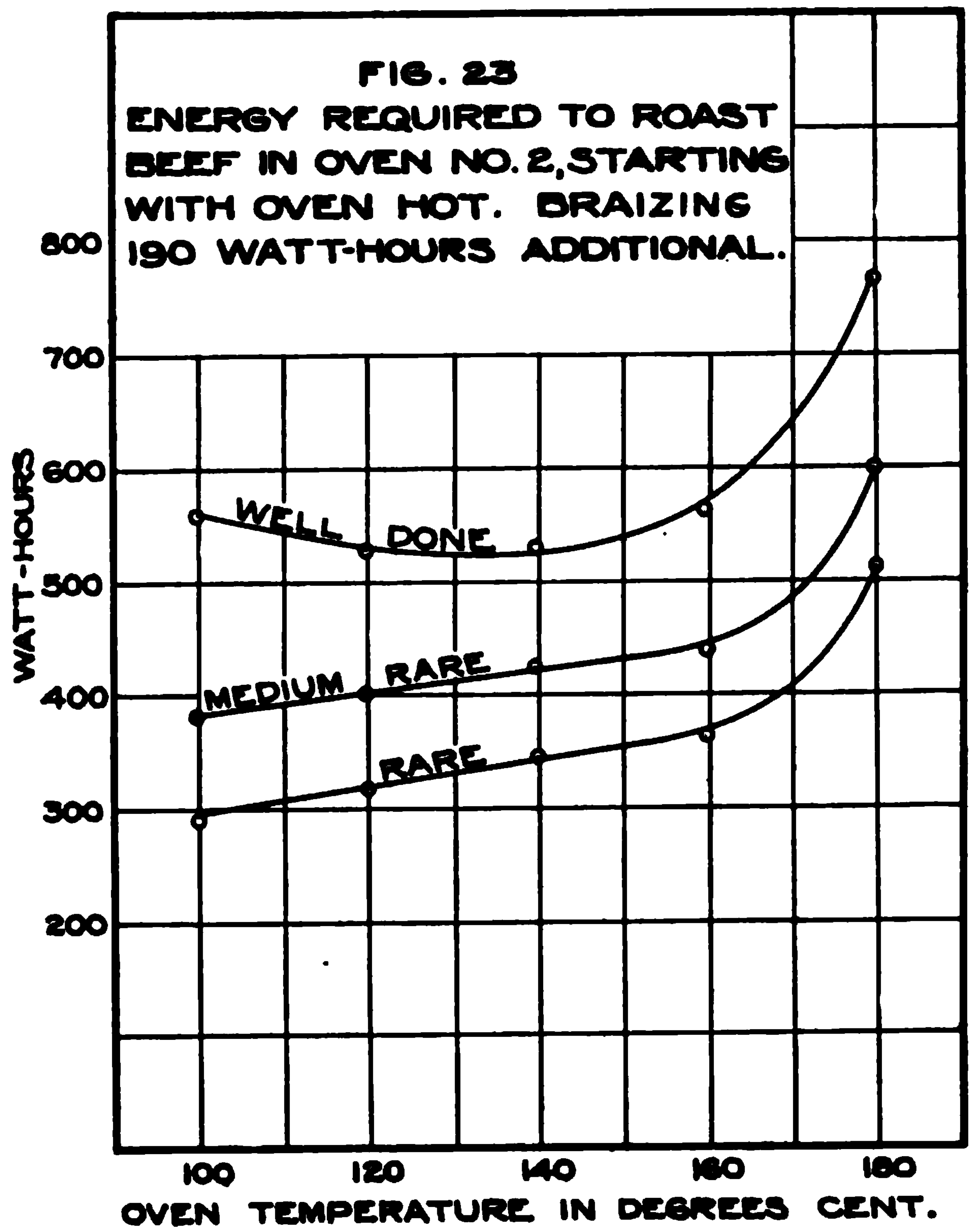


FIG. 22
ENERGY REQUIRED TO ROAST BEEF IN OVEN NO. 1, STARTING WITH OVEN HOT. BRAIZING 180 WATT-HOURS ADDITIONAL

the best accuracy were obtainable by this method it does not tell much about the actual cost of roasting meat. It well emphasizes the fact, which was discussed in a previous paragraph, that the method of measuring the efficiency of a steam boiler is not adaptable to cooking apparatus. According to the curve just obtained, the energy required for roasting beef at 180°C. (356°F.) ought to be less than at lower temperatures. Quite the contrary is true, however. At 180°C. more heat units are absorbed by the meat than at lower temperatures, but

this excess of heat in the meat is detrimental to its quality. The extra amount of heat is used to cause a larger loss in weight of the meat as shown by the curve in Fig. 19. It also chars the outside of the meat, forming a heavy crust which is very indigestible.

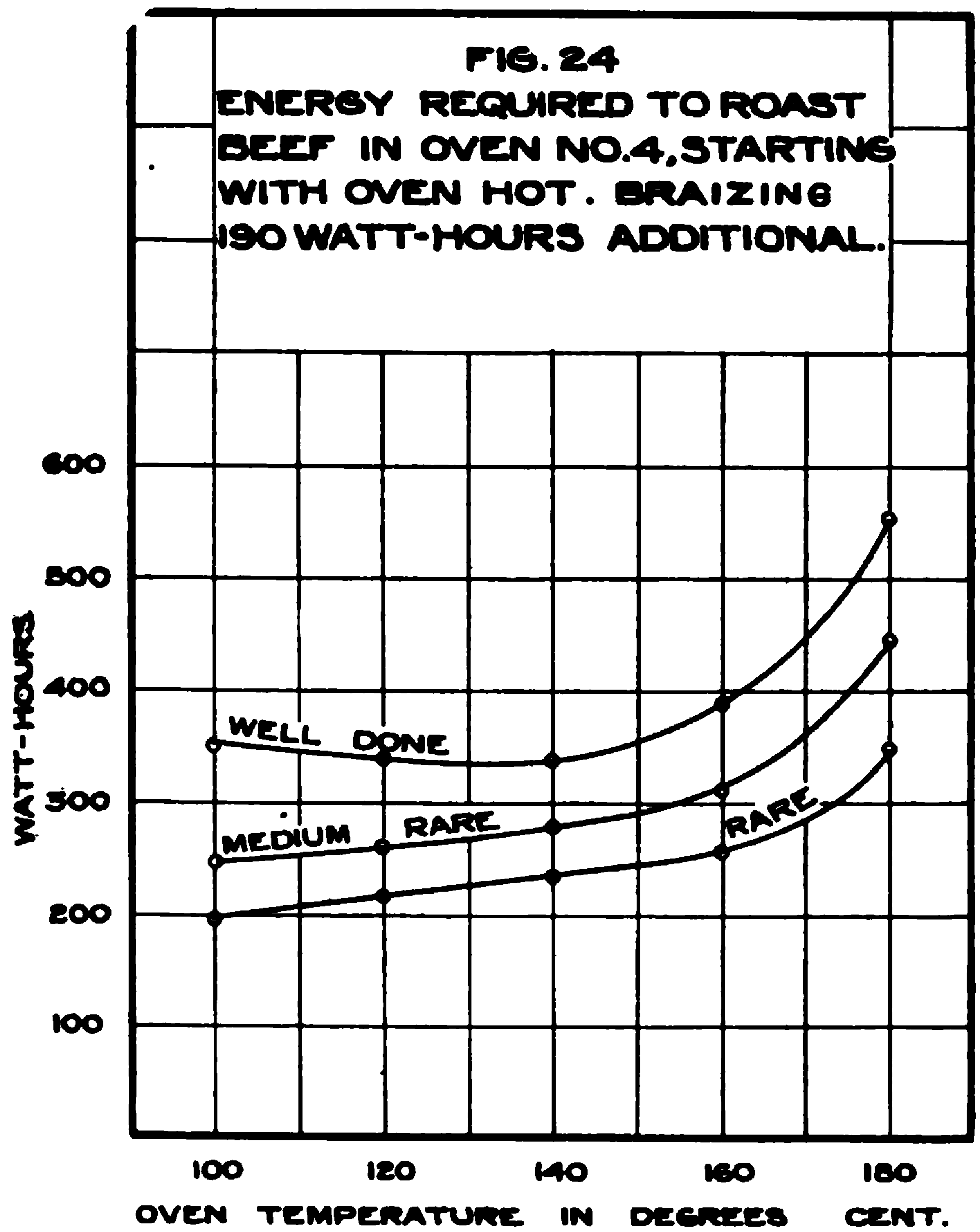
The curves of Figs. 22, 23, and 24 give the energy used in roasting beef in ovens Nos. 1, 2, and 4, starting with the oven at the required temperature. The energy used in braizing (or searing) the roasts is



not included in the ordinates to these curves, since it was the same in all cases, 190 watt-hours. It will be noticed that for rare roasts 100°C. (212°F.) is the most economical temperature in all the ovens, and for medium rare 100°C. is the most economical temperature except for oven No. 1 for which 120°C. to 140°C. (248°F. to 284°F.) is the best. The difference in this case is very slight, however, and within the probable error so that 100°C. could be used economically

even here if desired. For the well-done roasts there is a decided difference in the cost of cooking the meat at the various oven temperatures. For all the ovens the most economical temperature for the well-done roasts lies between 120° and 140°C.

When it is necessary to heat up the oven from room temperature different curves are obtained as shown in Figs. 25, 26, and 27. It



will be noticed that the rare and medium rare curves are much steeper and the difference in cost in favor of 100°C. is greater. For ovens No. 1 and 2 120°C. (248°F.) is the most economical temperature for well-done roasts while for oven No. 4, 100°C. is the best. With the cost of electricity at 5 cents per kilowatt-hour for oven No. 1 the difference between the cost of roasting meat at 100°C. and at 180°C. is 2 cents for rare, 2½ cents for medium rare, and for well-done the difference between 120°C. and 180°C. is 2½ cents. The saving in the

month's bill for the average family would probably amount to about 50 cents. It is well worth considering, however, since by observing these economies electric cooking will be able to compete with the cheaper fuels.

It will be noticed that the energy required for roasting meat in oven No. 1 is considerably greater than in ovens No. 2 and 4. This is due partly to the smaller amount of heat insulation used and partly

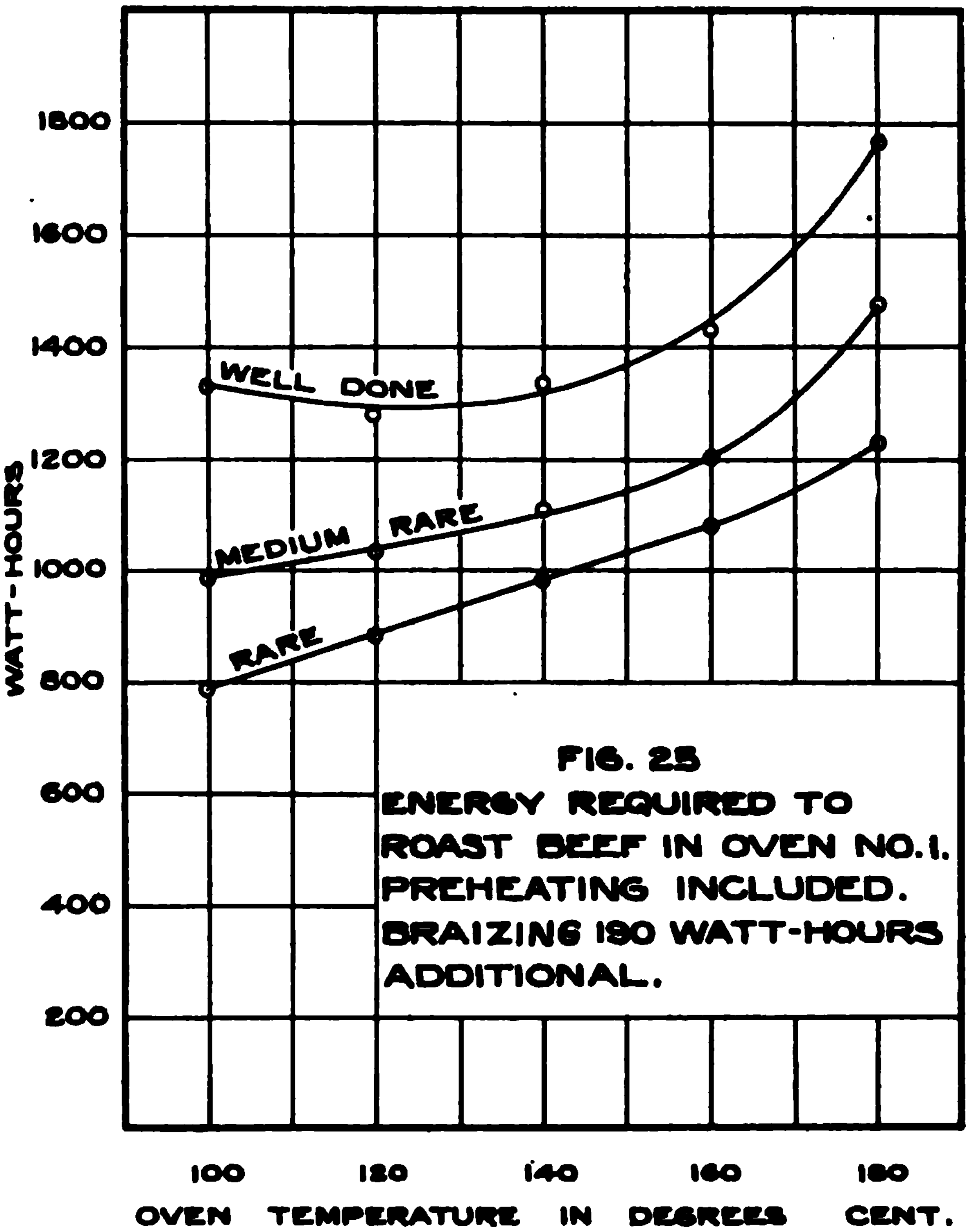


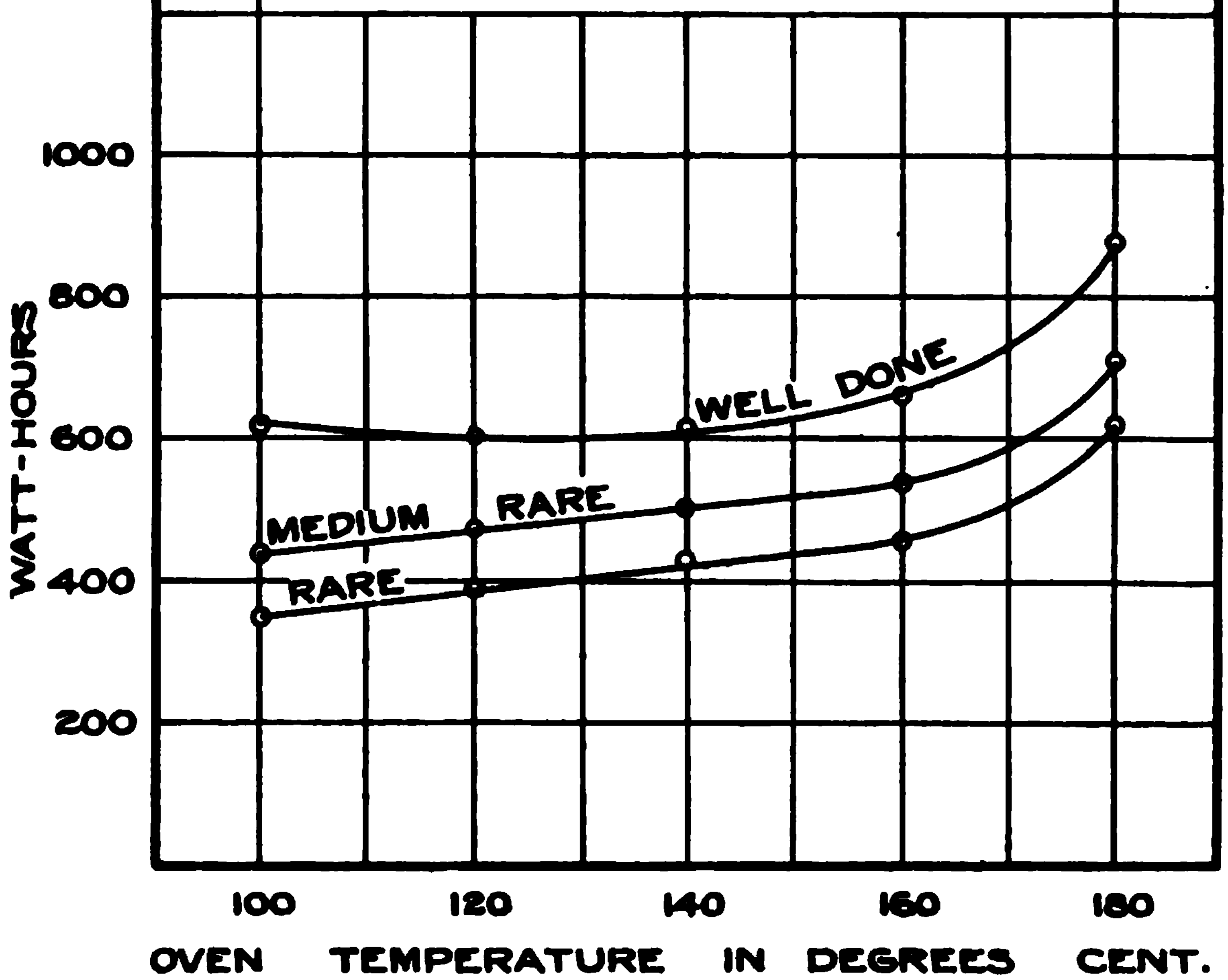
FIG. 25
ENERGY REQUIRED TO ROAST BEEF IN OVEN NO. 1. PREHEATING INCLUDED. BRAIZING 190 WATT-HOURS ADDITIONAL.

to the larger size of the oven. The oven was much larger than was necessary for cooking this size of roast. On this account both the radiation losses and the preheating loss were much greater than in the smaller ovens.

The energy curves just described were obtained in the following manner: The radiation loss was calculated for the required time of cooking. To this was added the loss due to opening the door and the

energy absorbed by the meat as given by the curves of Fig. 20 and 21. The values thus obtained were checked for 100°C. (212°F.) and 160°C. (320°F.) by cooking roasts at these temperatures in ovens No. 2 and 4. Oven No. 3 was tried at 160°C. but the heating element was found inadequate to maintain the required temperature in the oven after the roast was placed therein. The energy curves for this oven were therefore not obtained.

FIG. 26
ENERGY REQUIRED TO ROAST BEEF IN OVEN NO. 2. PRE-HEATING INCLUDED. BRAIZING 190 WATT-HOURS ADDITIONAL.



An experiment was tried by braizing the roast in the manner recommended by the cook books. The oven was heated to 250°C. (482°F.) the roast was placed therein, and full current was turned on until the temperature had returned to the desired value. The current was then turned off and the oven allowed to cool down to 100°C. (212°F.) where it was kept constant during the remainder of the experiment. The energy required for preparing the roasts by both methods is given in the following table:

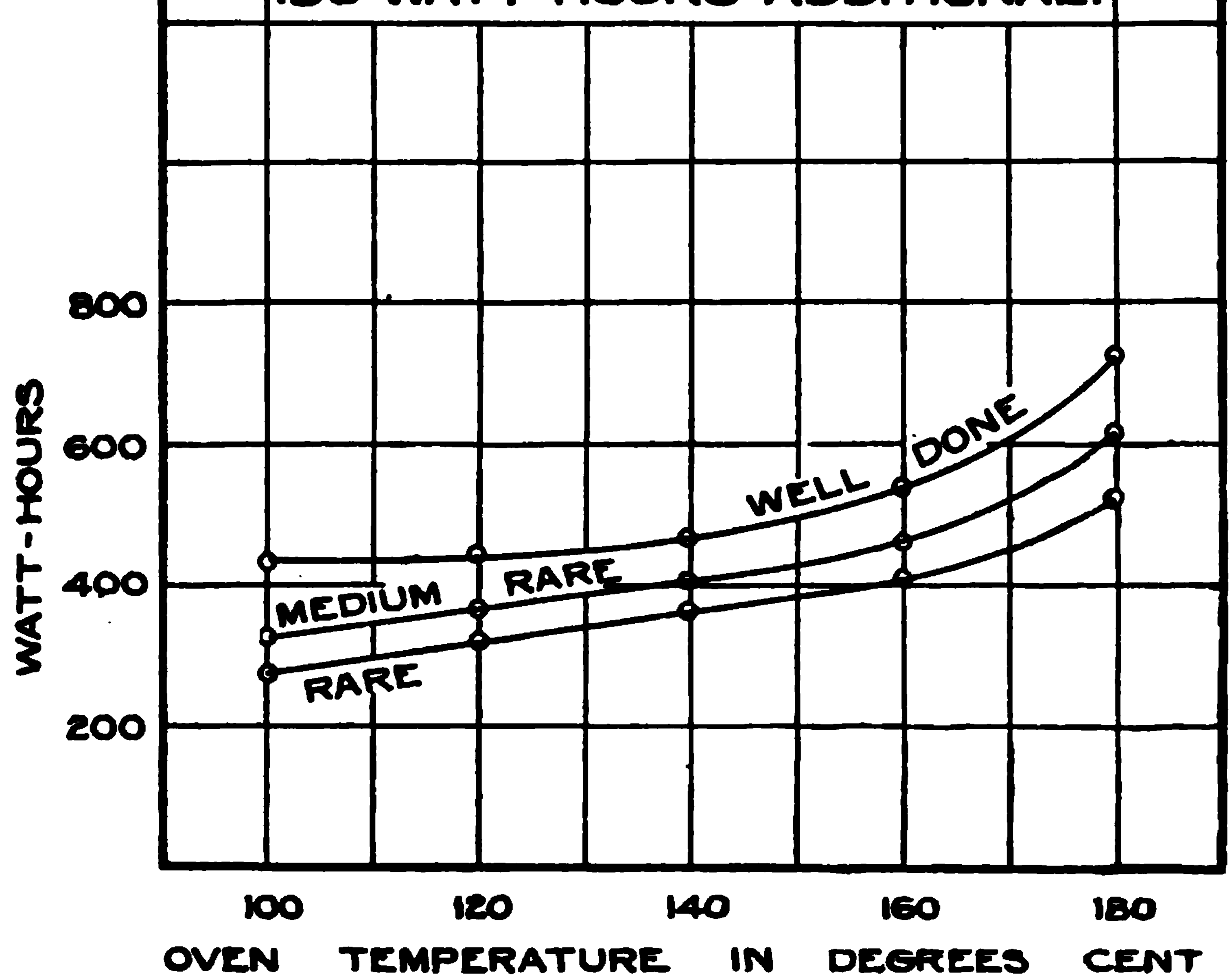
Table VII.

Watt-hours used in preparing roasts by the two methods of searing

	Searing on top coil	Remainder of test in oven at 100 °C. (212 °F.)	Total	Total when seared in oven	Difference
Rare........	190	790	880	1950	1070
Well done....	190	1325	1515	2580	1065

The saving in energy in favor of searing on top of the stove is surprisingly great, making a difference of 5 cents (at five cents per

FIG. 27
ENERGY REQUIRED TO ROAST BEEF IN OVEN NO. 4. PRE-HEATING INCLUDED. BRAIZING 190 WATT-HOURS ADDITIONAL.



kw-hr.) in the cost of preparing the roast. This great difference in the energy used by the two methods is due to the fact that when searing the meat in the oven the whole oven had to be heated up to the high temperature of 250°C. (482°F.) resulting in large preheating and radiation losses, while by the other method only the heating element, the dish, and the outside surface of the roast are heated to the high temperature. The losses are consequently greatly reduced.

Boiling meats. Electric insulated ovens of the proper construction are particularly adapted to boiling meats or rather cooking in water at the desired temperature. This process requires a long time and a low degree of heat.

The researches of Grindley [1] have disposed of the theory that meat should be first placed in water at the boiling temperature for ten minutes to seal up the outside. He says, "Thoro investigation confirms the conclusion that when meat is cooked in water at from 80° to 85°C. (176° to 185°F.), placing the meat in hot or cold water at the start has little effect on the amount of material found in the broth." The most economical method of boiling by means of electricity is, therefore, to immerse it in water and place it in the oven without preheating. If a small well-insulated oven is used and the dish placed directly on the heating element without a baffle, the meat can be cooked by using only a small amount of electricity.

Experiments on the temperature of coagulation of proteid and the decomposition of oxyhaemoglobin, the red coloring matter of meat, indicate that the probable lowest temperature of cooking meat is in the neighborhood of 75°C. (167°F.). One hundred degrees centigrade, the boiling point of water, will be the highest temperature used and the most economical temperature will be somewhere within this interval.

The increased popularity of the fireless cooker indicates that people are learning that food can be cooked below the boiling temperature and that meat is more tender and appetizing when cooked at 80°C. than at 100°C. as shown by many experiments. Cheap cuts of meat can be used and sometimes made nearly as attractive as the more expensive cuts cooked in the ordinary way.

No experiments were undertaken on cooking meats in water, hence no definite data can be given as to the amount of electricity required for such cooking.

BAKING EXPERIMENTS

Owing to a lack of definite information on the time and temperature of baking, a series of experiments were undertaken on the baking of biscuit, bread, and sponge cake. The purpose of the experiments

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1. Losses in Cooking Meat, U. S. Dept. of Ag. Bul. No. 141, p. 95.

was to determine the range of temperatures within which each article of food could be satisfactorily baked and the particular temperature within this interval which was the most economical for the ovens tested.

The method used was to determine the minimum time of baking at several oven temperatures. The experiments at a particular temperature were started at what was thought to be the proper time of baking at that temperature. If the condition of the food was well done and well browned the time of baking was reduced. This process was repeated until under-done samples were obtained. The shortest time of baking which gave satisfactory results was taken for that particular temperature. This was repeated for several oven temperatures and curves were plotted between the temperature of oven and the minimum time of baking. Each sample was carefully weighed before and after baking and the per cent loss of weight determined. The per cent loss of weight obtained at the minimum time of baking was then plotted against the oven temperature. Each point obtained on this curve was the mean of three determinations. The experiments were first performed in Oven No. 1 and were then checked in the other ovens.

Because of the short time of cooking and the small amount of food used in each sample it was not found possible, as in the meat experiments, to get accurate measurements of the amount of heat absorbed by the food. Consequently the amount of energy used in baking at the various temperatures in each oven was taken as the sum of the losses.

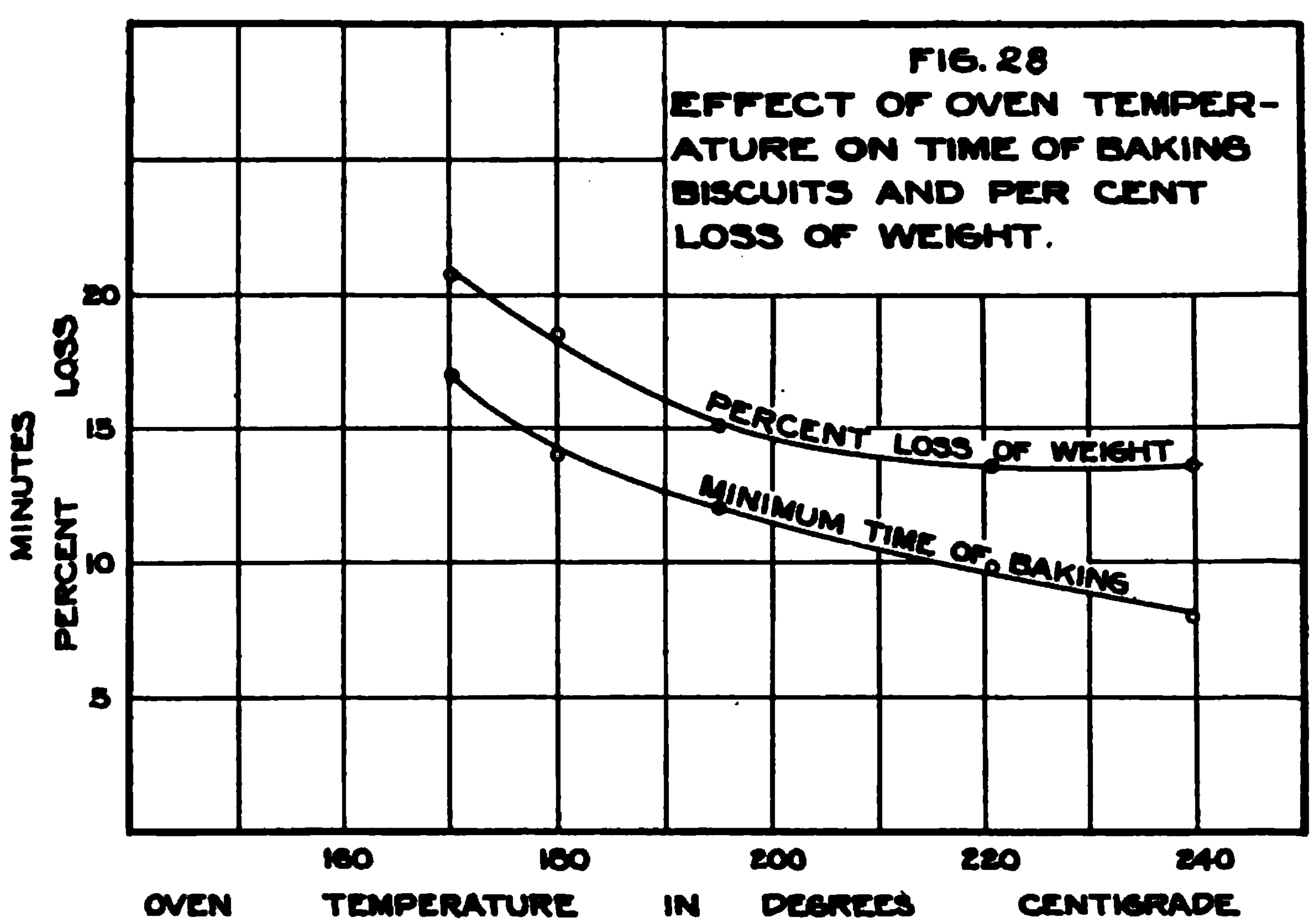

FIG. 28
EFFECT OF OVEN TEMPERATURE ON TIME OF BAKING BISCUITS AND PER CENT LOSS OF WEIGHT.

Fig. 28 shows the minimum time of baking and the per cent loss in weight curves for biscuits. Each sample consisted of six biscuits, the total sample weighing approximately 25 grams. They were prepared according to the following recipe:

1 cup of flour,
1 tablespoonful of lard,
½ teaspoonful of salt,
2 teaspoonfuls of baking powder,
enough milk to make a soft dough.

It will be noticed from the curves that the per cent loss of weight begins to increase very rapidly as the temperature decreases below 200°C. (392°F.). This increase in the loss of weight of the biscuits at the low temperatures indicated that the samples dried out to a greater extent due to the increased time of baking. This was very evident in the character of the biscuits prepared at these temperatures. They were dry and hard and had a heavy crust, instead of being crisp and tender. At 200°C. and above there was no difference discernible in the character of the samples. The range of temperature, therefore, for baking biscuits prepared according to the above recipe is from 200° to 240°C. (392° and 464°F.). Table VIII which gives in detail the results of the biscuit experiments will make clear the method used.

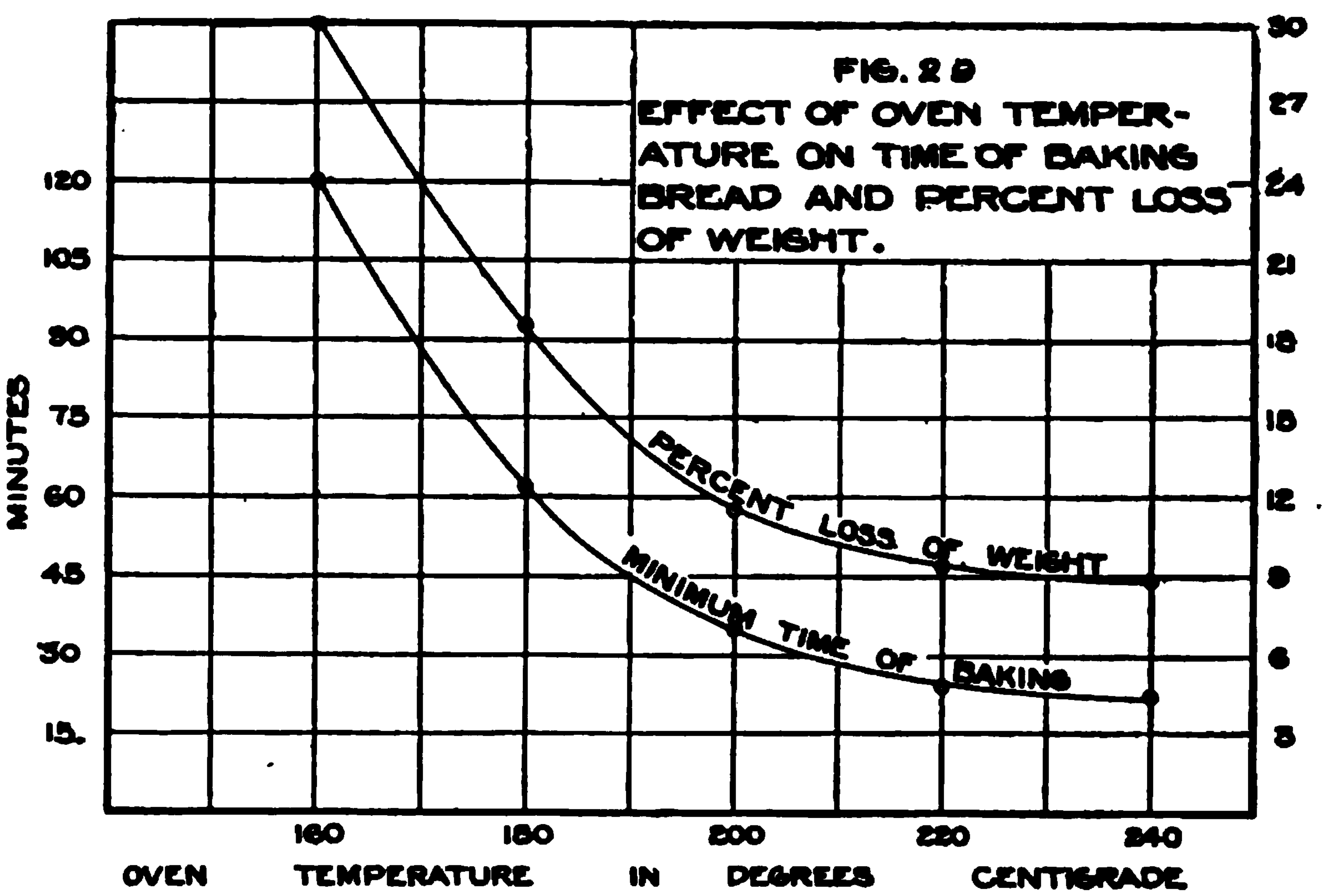

Fig. 29 shows the minimum time of baking and the per cent loss of weight curves for the bread experiments. The loaves averaged 300 grams in weight and were baked in a tin the dimensions of which were 3 inches by 5 inches by 3 inches deep. The bread was prepared according to the following recipe:

Table VIII—Biscuit Experiments

Time of baking	Oven temperature		Percent loss of weight	Condition of sample
	Cent.	Fahr.		
Minutes				
10	239.5	463.1	15.8	well done, well brown
10	239.5	463.1	15.5	well done, well brown
10	240.0	464.0	15.9	well done, well brown
8	239.5	463.1	12.9	well done, well brown
8	239.0	462.2	14.9	well done, well brown
8	240.0	464.0	13.0	well done, well brown
7	241.0	465.8	10.1	slightly brown, doughy
7	240.5	464.9	10.8	slightly brown, done
7	240.0	464.0	10.1	slightly brown, almost done
10	220.0	428.0	13.0	well done, well brown
10	221.0	429.8	12.9	well done, well brown
10	221.0	429.8	14.4	well done, well brown
10	220.0	428.0	14.3	well done, well brown
9	220.0	428.0	12.9	not brown, doughy
9	221.0	429.8	12.2	slightly brown, done
12	195.0	383.0	14.2	well done, well brown
12	194.0	381.2	15.1	well done, well brown
12	196.0	384.8	15.9	well done, well brown
10	195.0	383.0	8.0	slightly brown, done
10	195.0	383.0	7.2	slightly brown, almost done
11	195.0	383.0	15.0	well done, slightly brown
11	195.0	383.0	13.6	almost done, brown
11	195.5	383.9	14.6	almost done, slightly brown
14	180.0	356.0	17.8	well done, well brown
14	180.5	356.9	19.2	well done, well brown
14	180.0	356.0	18.8	well done, well brown
13	180.0	356.0	13.0	slightly brown, almost done
13	180.0	356.0	11.6	well done, well brown
13	180.5	356.9	14.3	brown, almost done
15	170.0	338.0	17.0	almost done, not brown
15	170.0	338.0	16.5	almost done, not brown
15	170.0	338.0	16.2	almost done, slightly brown
16	170.5	338.9	10.7	done, slightly brown
16	170.5	338.9	13.3	done, slightly brown
16	169.5	337.1	12.7	almost done, slightly brown
17	170.0	338.0	20.9	well done, brown
17	170.0	338.0	20.2	well done, brown
17	170.0	338.0	21.2	well done, brown

½ cup of water,
½ cup of milk,
1 teaspoonful of lard,
¼ teaspoonful of salt,
1 tablespoonful of sugar,
enough hard wheat flour to make a soft dough,
yeast.

In the bread experiments the most satisfactory results were obtained above 180°C. (356°F.). At the lower temperature the crust was hard and thick due to excessive evaporation of moisture as indicated by the loss in weight curve. At 240°C. (464°F.) the outside of the loaf had a tendency to brown over before the inside was thoroly done. So many factors other than the time and temperature of baking affect the texture and quality of the bread that no attempt was made to accurately score the loaves baked. The quality of flour, the proportion of the ingredients, and the manipulation before baking[1] all affect the flavor, quality, and texture of the loaf. It may be stated, however, that the range of temperature for baking bread in the above sized loaves lies between 180° and 240°C. The size of pan used was smaller than is used in the average household and the time required for baking a larger loaf would be somewhat longer.

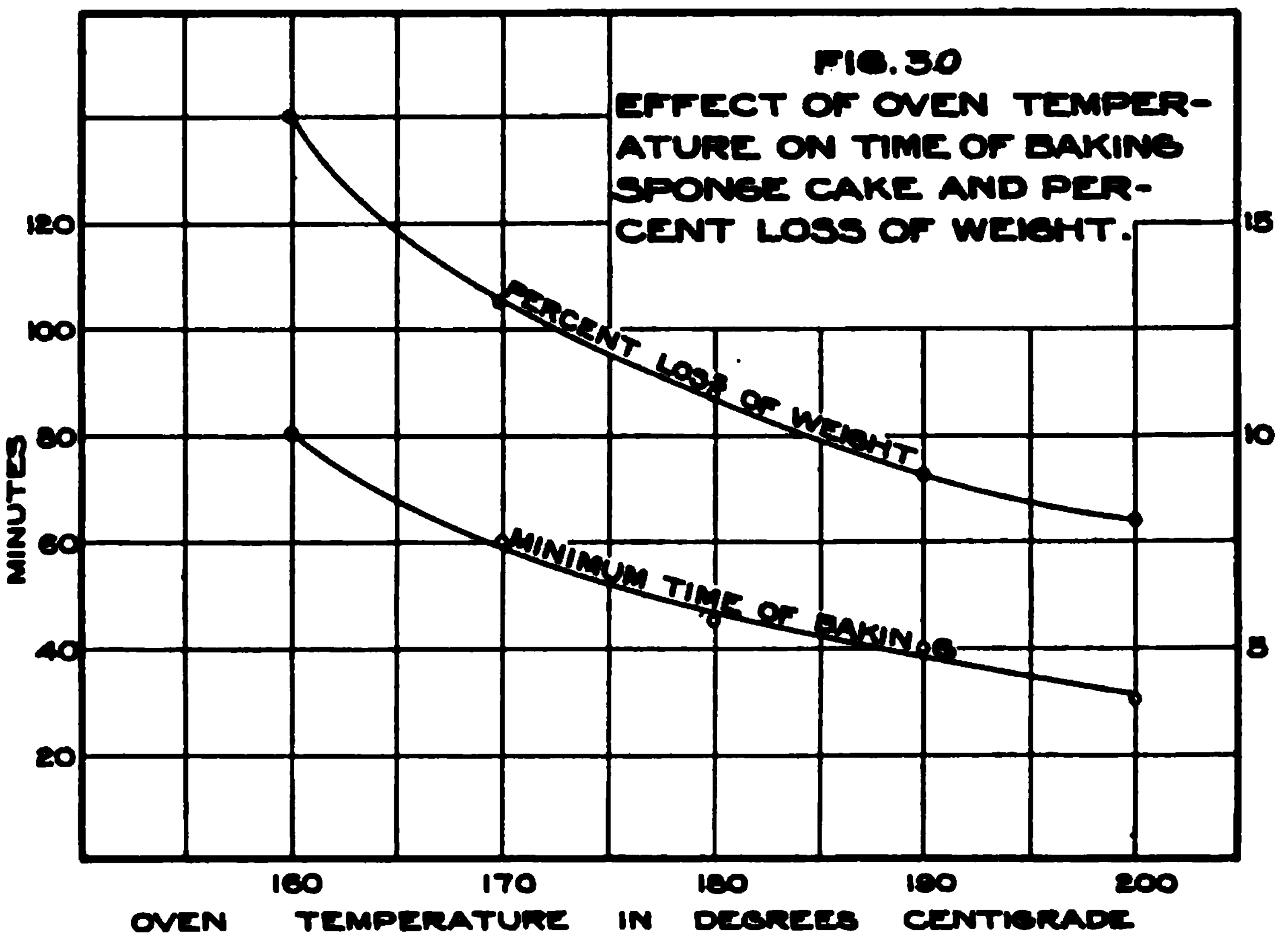

Fig. 30 shows the minimum time of baking and the per cent loss of weight curves for the sponge cake tests. The cake was prepared according to the following recipe:

4 eggs,
1 cup of sugar,
1 cup of flour,
1 tablespoonful of lemon juice.

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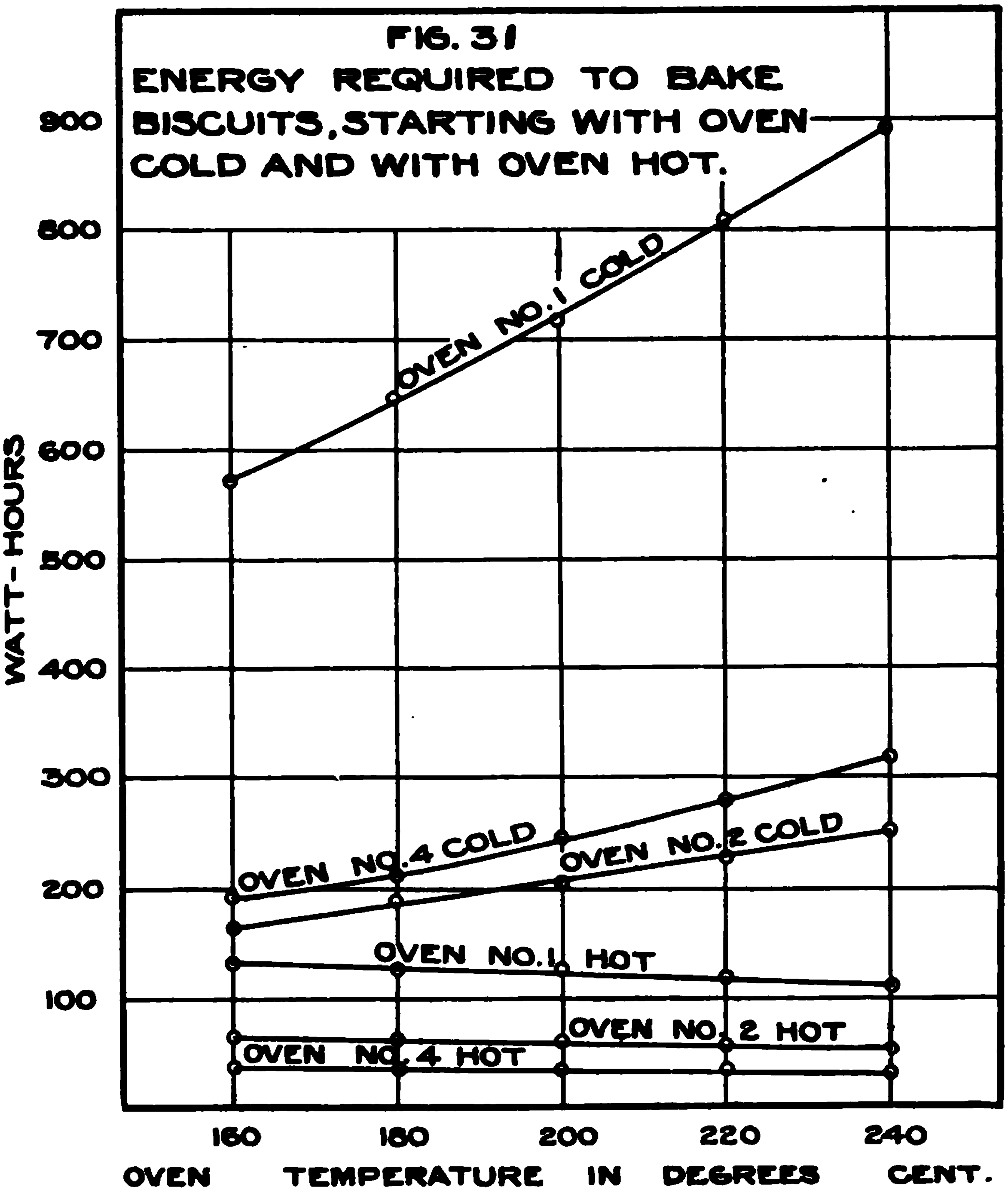
1. Univ. of Ill. Bull. Vol. X, No. 25.

The loaves averaged 250 grams in weight and were baked in a tin dish of the following dimensions: 5.5 inches by 4.2 inches by 2.5 inches deep.

The lowest temperature that should be used for baking sponge cake is approximately 170°C. (338°F.) as the crust becomes very heavy and thick at the lower temperatures due to the long baking and

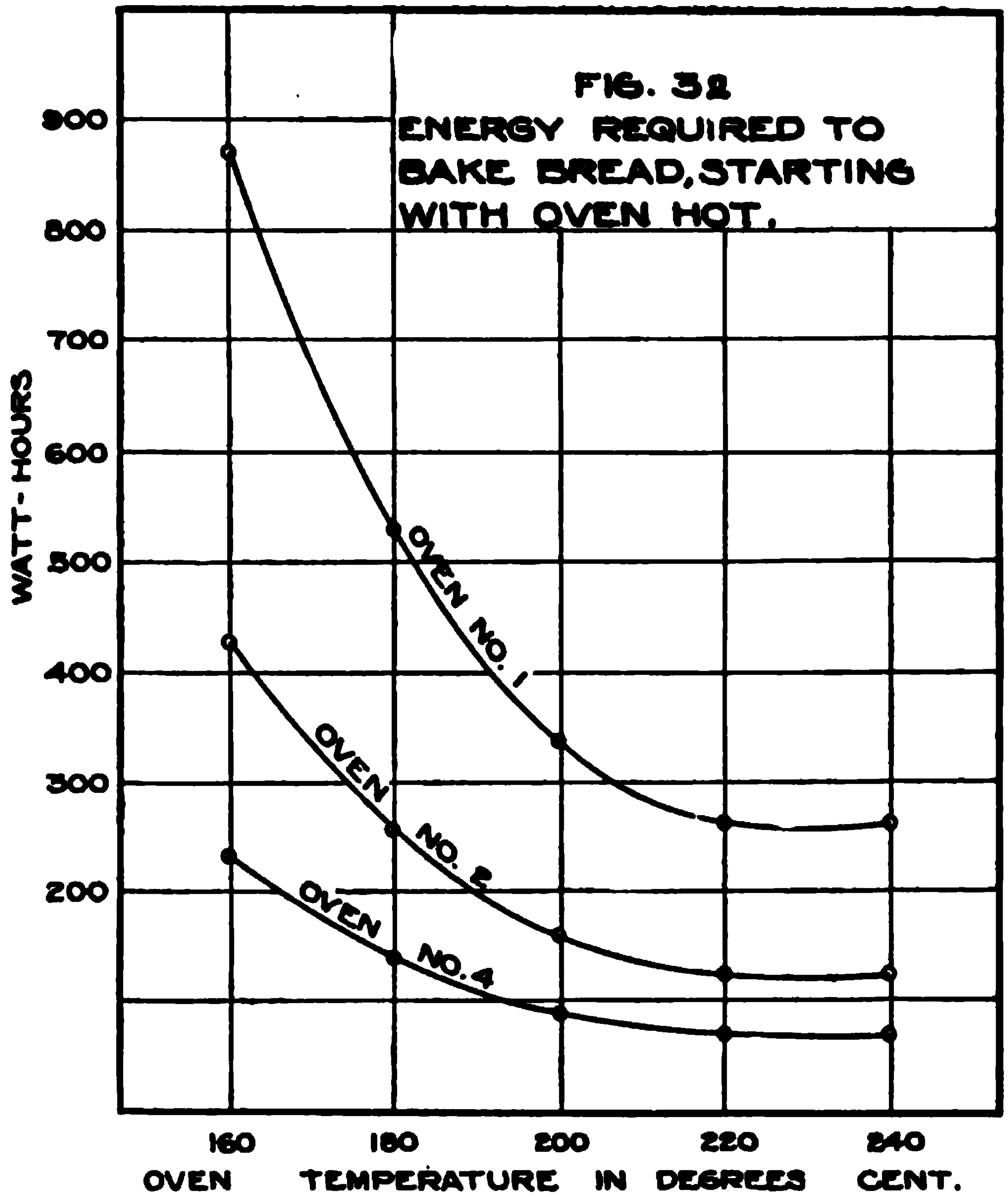
FIG. 31
ENERGY REQUIRED TO BAKE BISCUITS, STARTING WITH OVEN COLD AND WITH OVEN HOT.



the large loss of moisture. Because of the larger proportion of liquid in the dough, sponge cake will stand a greater loss of moisture than bread or biscuits. At 200°C. (392°F.) the loss of moisture was evidently too small as the texture of the crumb was not as good as the

samples baked at lower temperatures. The range of temperature, therefore, for baking sponge cake lies between 170° and 200°C. (338° and 392°F.).

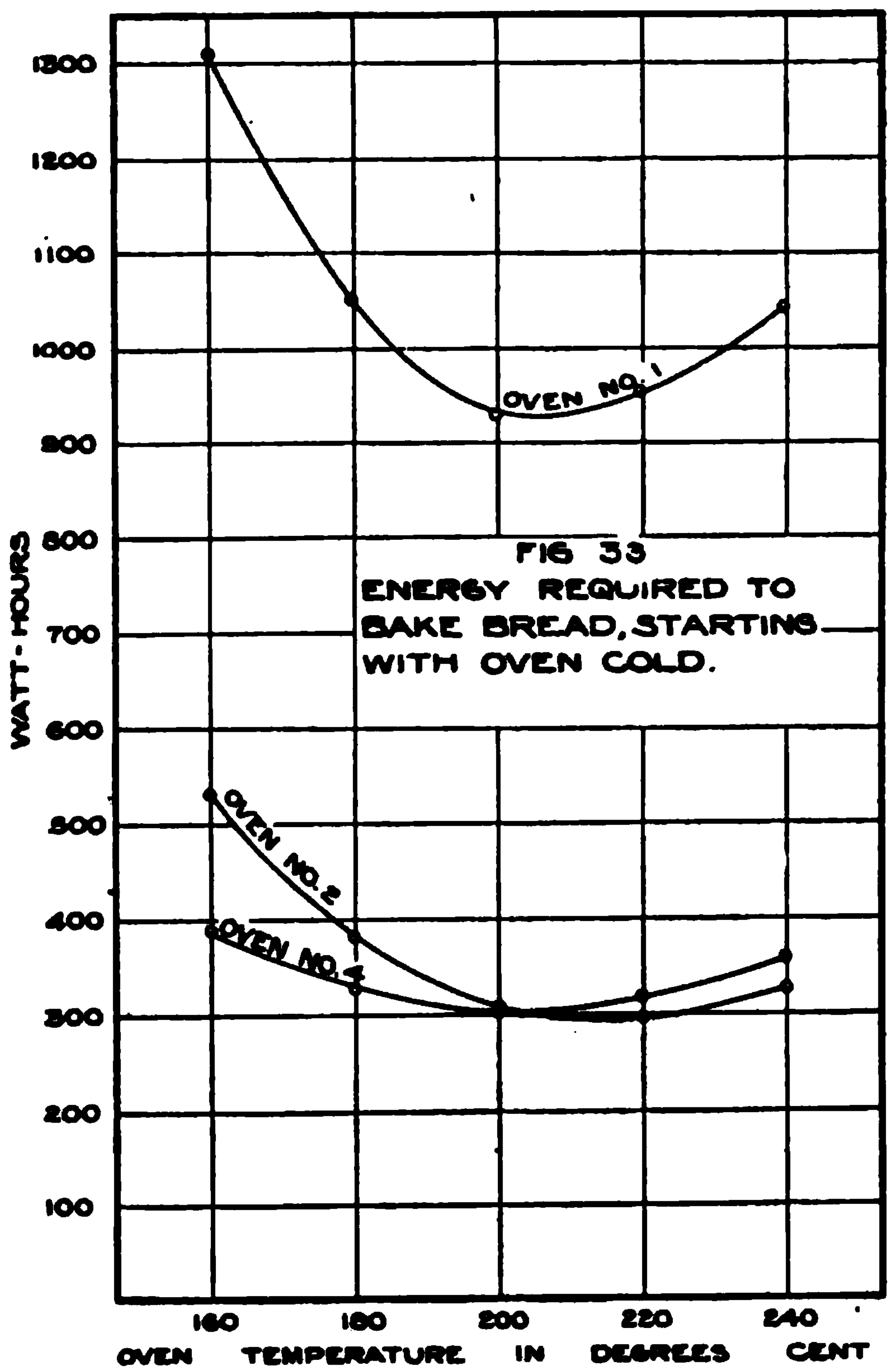
The curves of Fig. 31 show the amount of energy used in baking biscuits at the various oven temperatures for ovens Nos. 1, 2, and 4 with and without preheating. The curves show that if biscuits are baked immediately after other food is removed from the oven so that preheating is not necessary the energy required will be very small compared to the amount required if the oven has to be heated up from room temperature to baking temperature. This is especially true of



oven No. 1. When the baking is begun with the oven already at the desired temperature, the energy used in baking biscuits is practically the same for all the temperatures tried; but when the oven has to be heated up from room temperature the energy used is considerably less at the lower temperatures. Since the quality of the biscuits baked at temperatures below 200°C. (392°F.) is not as satisfactory as at higher

temperatures, these temperatures are not recommended. Two hundred degrees Centigrade is, therefore, the most economical temperature for baking biscuits when preheating is necessary.

Because the conditions of baking biscuits satisfactorily are a high temperature for a short time, the greater part of the energy required will be used in preheating. Consequently ovens used for baking biscuits should require as little energy as possible for preheating. This

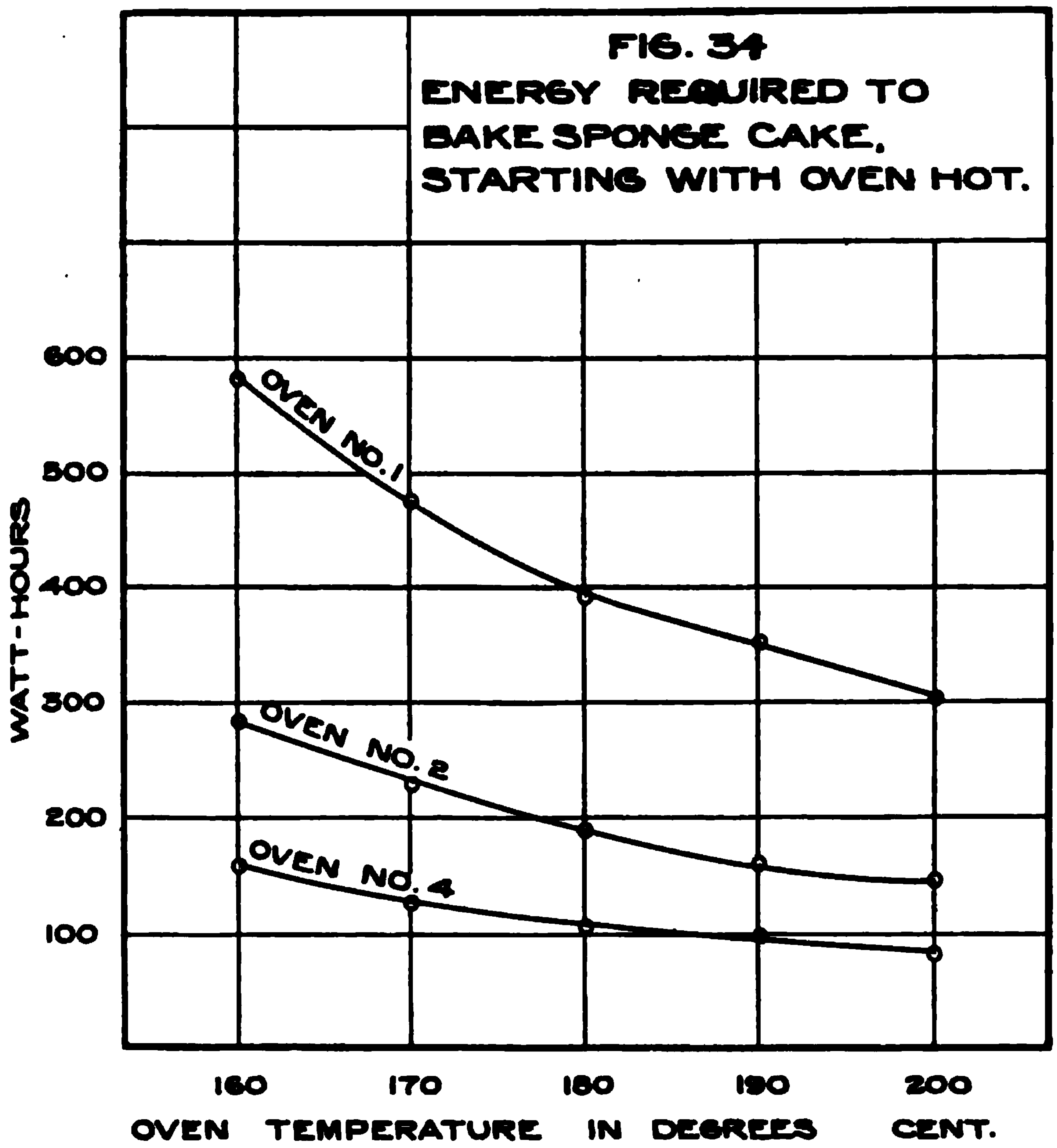


can be accomplished to a certain extent by using as small an oven as is practical.

Biscuit samples were also baked in ovens Nos. 2, 3, and 4. In oven No. 2 the biscuits did not brown satisfactorily on top as there was no heating element in the top of the oven. Oven No. 3 was found to be unsatisfactory for baking biscuits because with the heating arrangement used it was difficult to get sufficiently high temperatures. The

biscuits baked in oven No. 4 were quite satisfactory. The time of baking and the per cent loss of weight checked with the values obtained for oven No. 1.

The curves of Fig. 32 show the amount of energy used in baking bread at the various oven temperatures without preheating. It will be noticed that for all the ovens the energy required is a minimum above



220°C. (428°F.). The most economical temperature for baking bread when the oven is already heated is, therefore, from 220° to 240°C. (428° to 464°F.).

The curves of Fig. 33 show the amount of energy used in baking bread at the various oven temperatures including preheating. The temperature for which the energy required becomes a minimum lies between 200° and 215°C. (392° to 419°F.) depending on the oven

used. Altho the insulation of oven No. 4 is very much better than that of oven No. 2, it will be noticed that above 205°C, oven No. 4 requires more energy for baking bread than oven No. 2. This is due to the larger amount of energy required for the preheating.

The curves of Figs. 34 and 35 show the amount of energy used in baking sponge cake at the various temperatures with and without

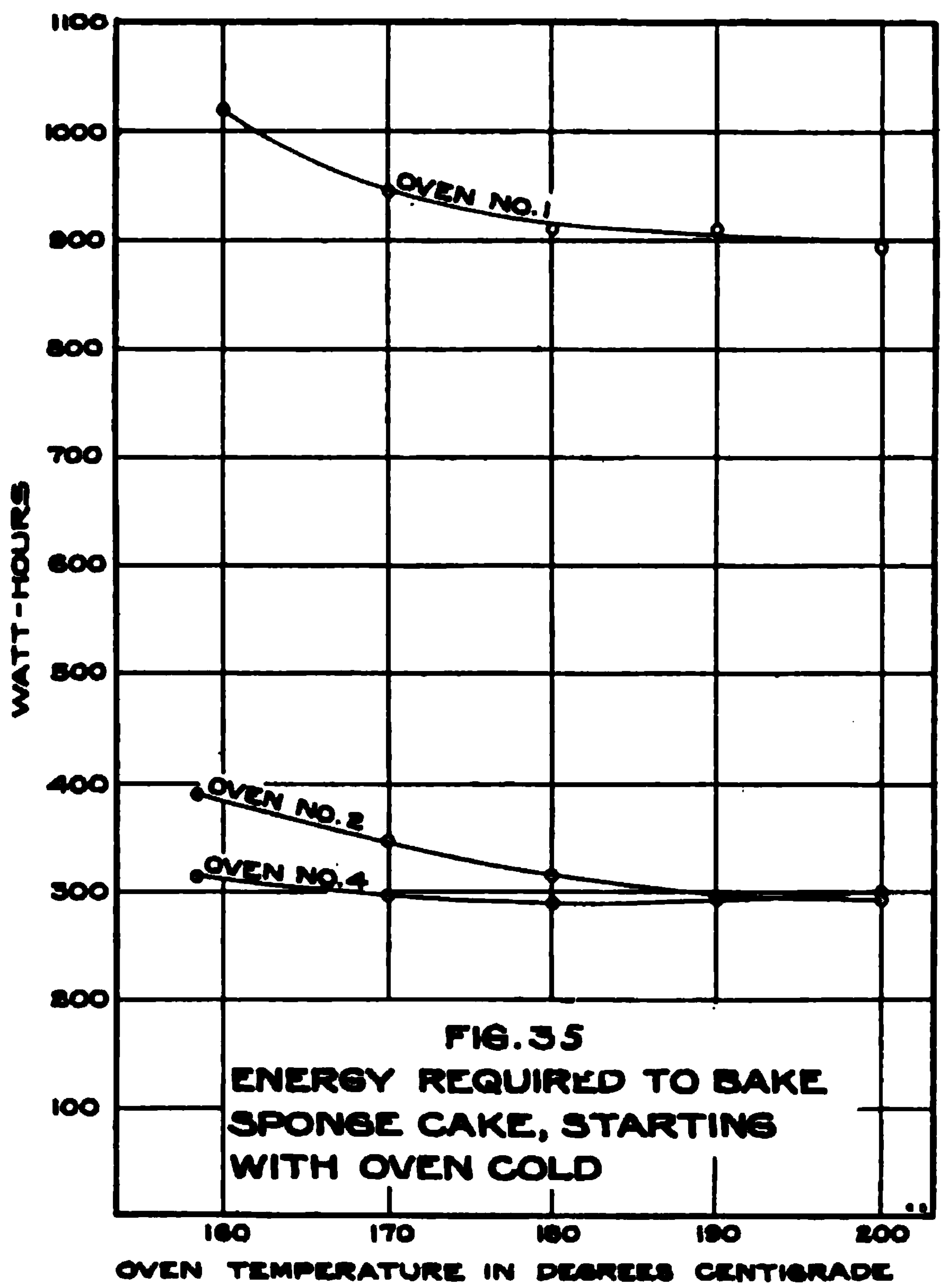


FIG. 35
ENERGY REQUIRED TO BAKE SPONGE CAKE, STARTING WITH OVEN COLD

preheating. As shown by the curves, the most economical temperature for baking sponge cake, when the oven is already heated, is 200°C. Except for oven No. 4 this is also the most economical temperature when the oven is started at room temperature. For oven No. 4, the most economical temperature is 180°C. but the difference in the energy required at 180° and 200°C. is slight. Because of the poorer quality obtained at 200°C, the best temperature for baking sponge cake will be between 180° and 190°C.

Consideration of the baking curves as a whole will emphasize the importance of the preheating characteristics in designing an efficient electric oven. For the kinds of baking which require a high temperature for a short time the preheating loss is considerably greater than the radiation and convection loss. Unless some method can be found for decreasing the energy used in heating the oven up from room temperature it will not be practical to increase the heat insulation of the ovens used for domestic baking. This does not apply, however, to ovens which are used for long intervals at the same temperature.

THICKNESS OF HEAT INSULATION

If a heat insulating material is placed between the inner and the outer surfaces of an electric oven, the radiation and convection losses will be reduced, due to the lower temperature of the outside surface, as explained in a previous paragraph. For the same internal temperature of the oven, the greater the thickness of insulation used, the lower will be the temperature of the outside surface and the smaller will be the losses. It would not be economical, however, to increase very greatly the thickness of the heat insulation as the cost of each additional inch increases rapidly and the effect of each additional inch on the amount of energy lost decreases even more rapidly. If, for a given insulating material, the number of hours per year that the oven will probably be used at the various oven temperatures and the cost of electricity are known, there is, evidently, a definite thickness of heat insulation for which the sum of the cost of the energy lost per year due to the radiation and convection and the annual cost of the insulation will be a minimum.

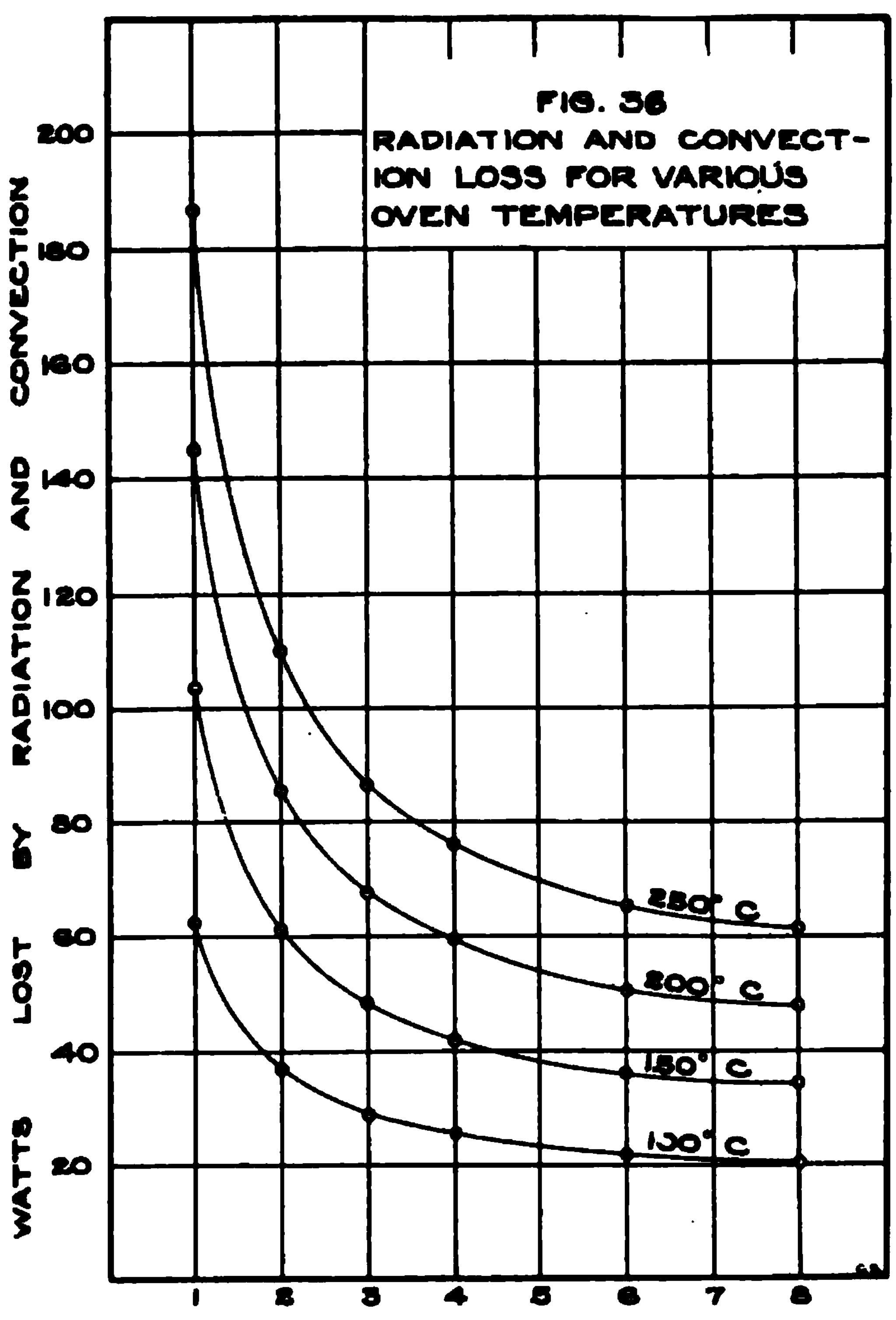
In order to obtain some data on the most economical thickness of heat insulation for electric ovens a series of experiments were undertaken. From one to eight inches of powdered kieselguhr was used for the heat insulation. A heating element and a thermo-couple were placed in a tin box 9 inches by 10.5 inches by 12 inches, which were the inside dimensions of ovens Nos. 2 and 4. This box was placed inside a larger box and the space between the two was filled with the insulating material. Care was taken to center the inner box accurately so as to obtain a uniform thickness of insulation on all sides. The insulation was packed gently and uniformly so that the density obtained was approximately twenty pounds per cubic foot.

The method used in each test was to connect the heating element to a source of constant potential and leave it until the inside temperature of the oven reached a constant value, when readings were taken of watts input and the oven temperature.

A copper constantan thermo-couple which had been calibrated by the Bureau of Standards was used to measure the oven temperature.

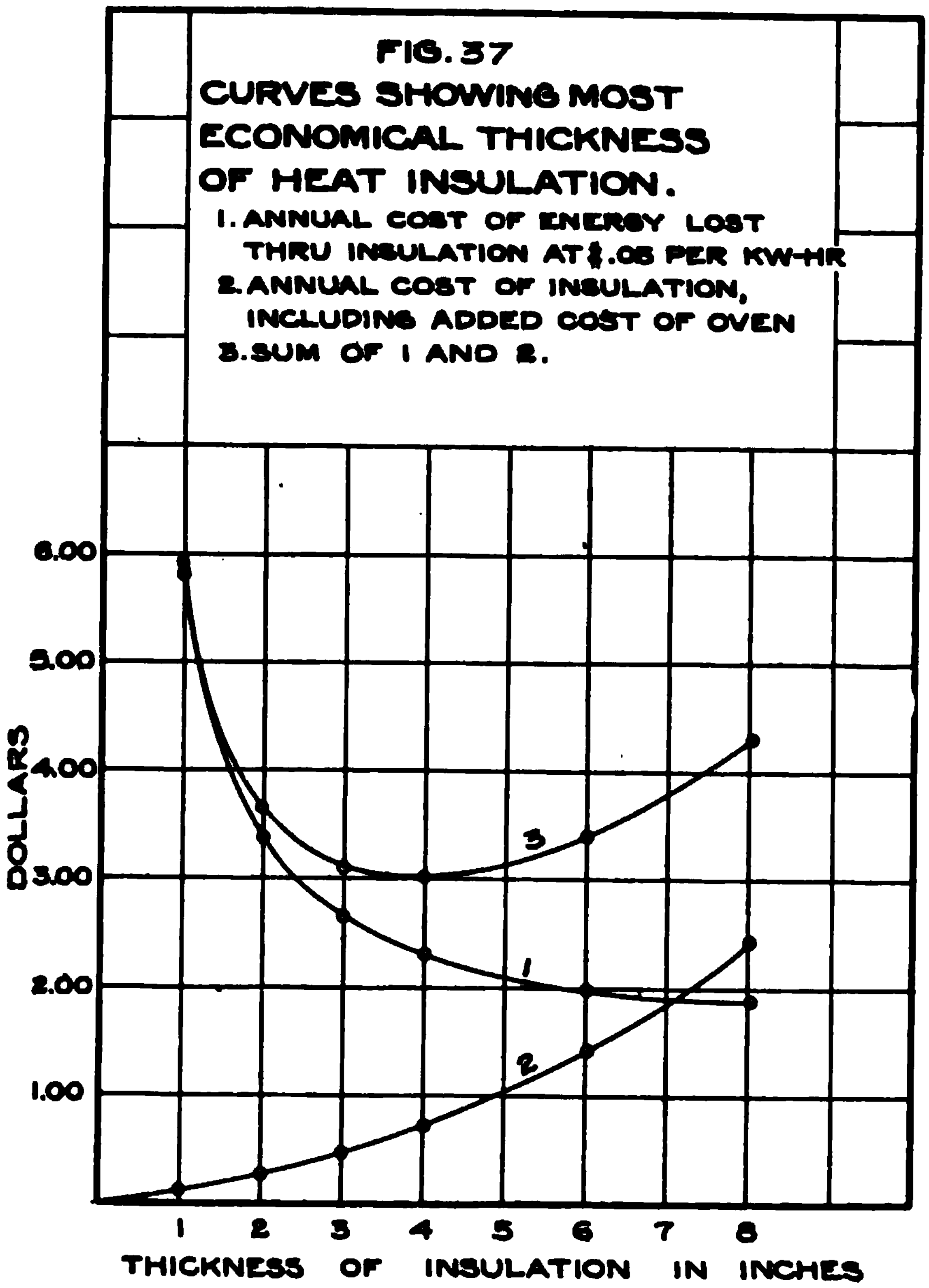
During the first part of each test it was connected to a Bristol recording galvanometer. After the internal temperature had remained constant for at least three hours the thermo-couple was connected to a potentiometer, by means of which the e. m. f. of the couple was accurately obtained. The cold junction was kept at 0°C. (32°F.) by immersion in ice water.

During the first few hours of each test the heating element was connected to the laboratory supply mains while for the last six hours of each test it was connected to a motor generator set, the voltage of



which was kept constant by means of a Tirrill regulator. Energy input was obtained from the readings of a voltmeter and an ammeter which had been carefully calibrated by comparison with Weston laboratory standards. The kind of external surface used in each test was new bright tin. The bottom surface rested on a cement floor.

The results of the experiments are given in Table IX since for a given thickness of heat insulation and low temperature of external oven surface the radiation and convection loss is approximately proportional to the difference between the room temperature and the inside temperature of the oven as shown in Fig. 11,—the loss for any oven temperature can be calculated. The curves of Fig. 36 show the relation between the thickness of insulation and the watts lost for oven temperatures of 100°, 150°, 200°, and 250°C. (212°, 302°, 392° and 482°F.).



If the number of hours per year that an oven of this size will be used at the various oven temperatures can be estimated, the cost per year of the radiation and convection losses can be calculated from these curves. In order to get a value for the most economical thickness of heat insulation, it is assumed that an oven of this size is to be used as follows:

100 hr. per yr. at 200°C. (392°F.)
150 hr. per yr. at 175°C. (347°F.)
400 hr. per yr. at 150°C. (302°F.)
750 hr. per yr. at 125°C. (257°F.)

It is also assumed that the cost of electricity for cooking is 5 cents per kilowatt-hour.

Curve 1, Fig. 37 shows the cost per year of the radiation and convection loss for various thicknesses of insulation. Curve 2 shows the cost of heat insulation used, at 2 cents per pound and twelve pounds per cubic foot. An accurate expression for the cost of adding extra insulation should include the extra cost of the outside covering of the oven, necessitated by the extra volume of insulation. As no data are available to the author concerning the cost of manufacture, it is assumed that for each thickness of insulation the manufacturing cost of parts of the oven affected by the thickness of insulation is three times the cost of the insulation itself. If an interest and depreciation charge of 25 per cent is assumed, curve 2 becomes the cost per year of insulating this size oven with various thicknesses of heat insulation. It is evident that for the most economical thickness of heat insulation the sum of curve 1 and curve 2 should be a minimum. This condition

Table IX.

Thickness of insulation, in.	Internal temp. degrees		Room temp. degrees		Watts loss
	Cent.	Fahr.	Cent.	Fahr.	
8	271.1	520.0	24	75.2	67.4
8	271.0	519.8	25	77.0	67.4
6	270.5	518.9	27	80.6	70.6
6	271.0	519.8	26	78.8	71.0
4	233.1	451.6	25	77.0	71.2
4	237.8	460.0	25	77.0	71.4
3	210.4	410.7	26	78.8	71.7
3	210.2	410.4	27	80.6	71.7
2	170.6	339.1	25	77.0	69.4
2	171.8	341.2	25	77.0	72.1
1	106.5	223.7	24	75.2	67.6
1	106.3	223.3	25	77.0	67.5

is fulfilled for an insulation thickness of four inches as shown by curve 3.

In a similar manner the most economical thickness of heat insulation for any given set of conditions can be determined. A limiting factor other than the cost of the insulation is the rapid increase in the size of the oven for the larger thicknesses. It is unlikely that insulation thicknesses more than four inches will be used for domestic purposes; because, for thicknesses above this value, the ovens become too large and cumbersome to use in the ordinary kitchen.

The results of the experiments just described indicate that a net annual saving would result if the commercial electric ovens now on the market were better insulated. There are several electric ovens now on the market which have as small as one inch of heat insulation. Even under the most favorable conditions this could probably be economically increased to two or three inches.

An objection that the designer of electric ovens may bring against an increase in the thickness of heat insulation is the danger to the oven if the automatic cut off fails to operate. The ovens now on the market are built to withstand the highest oven temperature obtainable with all the coils turned on full. This design is necessary at present because of the lack of a cheap and reliable automatic release. As an auxiliary to a mechanical release, a heat fuse might be constructed so as to melt due to the internal temperature of the oven if the mechanical release failed to operate. For ovens operating at 100°C. (212°F.) or less, pure tin might be used and zinc for ovens using higher temperatures. Even if the retail price of such a fuse should be high, their use would not be prohibitive as they would blow only when the automatic release failed to work.

Kieselguhr was chosen as the heat insulating material in the above experiments as it is the cheapest of the good heat insulators which will stand medium high temperatures; its melting point being[1] 1610°C. (3930°F.).

Of other materials used for heat insulation of electric ovens silox, mineral wool, and non-pareil insulating brick also give good results. No experiments were made by the author, however, to determine the relative advantages of each. Cork board was used on one of the experimental ovens constructed; but altho it is a very good heat insulator it is not to be recommended for oven temperatures above 100°C. (212°F.) on account of its combustibility.

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1. Met. & Chem. Engr., vol. 12, p. 112.

SUMMARY

1. The radiation and convection loss from an insulated electric oven can be obtained for any oven temperature below 250°C. (482°F.) by measuring the maximum temperature of the oven for a given energy input plotting these values and drawing a straight line thru the point thus obtained and zero energy at room temperature.

2. The preheating loss of an electric oven can be obtained by taking simultaneous readings of watt-hours and oven temperature. For domestic use the preheating loss should be made as small as possible by decreasing the heat capacity of the oven as much as is practical and by using a large coil for the preheating.

3. The energy lost when the door of an electric oven is opened for fifteen seconds was determined for various oven temperatures. For an oven temperature of 200°C. (392°F.) used in baking bread, biscuits, etc. the loss due to opening a 12-inch by 18-inch oven door for fifteen seconds amounted to twelve watt-hours. At 5 cents per kilowatt hour for electric current this would mean a cost of six one-hundredths of a cent each time the door was opened for a period of fifteen seconds. (See Fig. 15.)

4. Since the purpose of cooking food is not to put as many heat units as possible into the food but is rather to improve its flavor and to increase its digestibility, the steam boiler method of determining efficiency is not applicable to electric ovens.

5. In order to compare the cost of cooking in various electric ovens a method proposed for indicating the relative efficiency of the electric ovens is to specify the amount of the preheating and the radiation losses at the required oven temperatures.

6. The time required for roasting a rolled rib roast of beef, rare, medium rare, and well done, was determined for various oven temperatures. The shortest time of roasting was at 160°C. (320°F.). (See Fig. 17.)

7. The per cent loss of weight of the roasts was found to increase with the oven temperature used. (See Table V.)

8. The energy required for roasting a rolled rib roast of beef in three types of electric ovens was determined for oven temperatures from 100° to 180°C. (212° to 356°F.). The most economical temperature for preparing rare and medium rare roasts was found to be 100°C. in each oven. For well done roasts 120°C. (248°F.) is the most economical temperature.

9. With electricity at 5 cents per kilowatt hour, it is at least 2 cents cheaper to roast beef at 100° to 120°C. than at 180°C.

10. It was found that at least 1000 watt-hours could be saved by searing the roast on top of the stove instead of heating the whole oven up to 250°C., a saving of five cents on the basis of 5 cents per kilowatt hour for electric current.

11. A method was devised for determining the most economical temperature for baking bread, cake, and biscuits. The minimum time of baking and the per cent loss of weight were determined for several oven temperatures. (See Table VIII.)

12. The range of oven temperatures for baking biscuits was found to be from 200° to 240°C. (392° to 464°F.). Starting with the oven at the required temperature, the energy used in baking biscuits is practically the same for all oven temperatures. If it is necessary to heat up the oven from room temperature the most economical oven temperature is the lowest which will give satisfactory results; i. e. about 200°C. (392°F.).

13. The range of temperatures for baking a small sized loaf of bread was found to lie between 180° and 240°C. (356° and 464°F.). Starting with the oven at the required temperature the most economical temperature for baking bread is between 220° and 240°C. When preheating is included, the most economical temperature for a small sized loaf was found to be between 200° and 215°C.

14. The range of temperature for baking sponge cake was found to lie between 170° and 190°C. (338° and 374°F.). For baking sponge cake the most economical oven temperature is the highest temperature which will give satisfactory results; i. e., about 190°C. (374°F.).

15. With electricity at 5 cents per kilowatt hour and allowing an interest and depreciation charge of 25 per cent, the most economical thickness of kieselguhr insulation was found for domestic use to lie between three and four inches.

CONCLUSIONS

Much has been accomplished recently by domestic scientists in substituting accurate scientific methods of cooking for the vague and indefinite rules of our grandparents. There is, however, an enormous amount of work yet to be done before an inexperienced person can hope to get uniformly good results without first experiencing many failures and wasting much good material.

With reference to the use of a thermometer for the standardization of oven temperatures Miss M. B. Van Arsdale,[1] assistant professor of household arts at Columbia University, says, "Regarding the inexperienced housewife it can truly be said that with an accurate thermometer her results would undoubtedly be more uniformly good—and we believe that the recipe books of the future should not read merely 'bake until done in a moderate oven' or 'according to judgment,' but will also state how long and at what temperature, so that in the hands of even the inexperienced these recipes will yield not occasionally good

1. Technical Educ. Bul. No. 22, Columbia Univ.

but uniformly good results without the discouragement of many failures, the sacrifices of much time and the waste of much good material. Thus the scientific treatment of the subject added to our traditional knowledge should tend to evolve an even higher type of cookery than we have had in the past."

The present lack of definite rules for cooking is due in a large degree to the absence of adequate means of controlling the temperature of the food. When using the ordinary wood or coal cooking range the degree of heat is controlled chiefly by dealing with the food itself rather than by regulating the heat at the point of combustion. The amount of draft necessary to promote the combustion of the fuel causes too great a degree of heat in the oven or on the stove to enable the cook to deal with the food in the proper way except by constantly watching it, stirring it, and changing the position of the vessel on the stove or in the oven.

With the advent of electric ovens a revolution in the methods of cooking has become possible. Not only can the temperature of the electric oven be accurately controlled but the necessity of constant vigilance is removed. Apparatus can be designed for making the whole process practically automatic. Some kinds of food can even be prepared in advance, placed in the oven, and without any further attention on the part of the housewife the current will automatically be turned on at a predetermined time. The temperature of the oven will increase to the desired value and there remain constant until the food is properly cooked.

With this method perfected the advantage of electric cooking over the other methods will be great and in most cases the cost will not be excessive. To the possibility of obtaining uniformly well-cooked food should be added the saving to the housewife in time and worry and the absence from the kitchen of excessive heat.

The present day problem in electric cooking is to determine the methods of cooking that will yield the most in nutrition and flavor and to formulate definite rules or directions so that a particular article of food can be cooked in the best possible manner by persons of ordinary skill. The engineer's problem is then to design practical cooking devices in which the temperature can be accurately regulated with a minimum of attention on the part of the housewife.

Electric cooking may be classified according to the temperature to be used in the oven. The baking of bread, cake, and pastry requires a high oven temperature. In the average family where the oven is used intermittently a large part of the electricity used in this class of baking will go to heat up the oven from room temperature to the required baking temperature. In other words the preheating loss will be large compared with the radiation and convection loss.

The preparation of vegetables, cereals, and meats (except for searing, broiling, and frying) requires a low degree of heat, applied

for several hours. In this class of cooking the preheating loss forms but a small part of the total loss, while the radiation and convection loss is a large part of the whole.

It is evident that the characteristics of properly designed ovens differ for the two kinds of cooking. An oven to be used for baking at the high temperature should have the preheating loss reduced to a minimum. A large-sized heating element should be used for the preheating and be automatically cut off as soon as the oven reaches the desired temperature. A smaller coil will then suffice to keep the oven at the required temperature by supplying enough heat to balance the losses and the heat absorbed by the food. Unless it is planned to frequently use the oven for several hours at the same temperature as in baking several batches of bread or cake, it will not pay to increase the heat insulation of the oven to such an extent as where the preheating loss is smaller. Since in cooking at the lower temperatures, the preheating loss is small compared with the radiation and convection loss, the latter then becomes the more important and a thicker heat insulation can be economically used.

For baking at the higher temperatures a heating element in the upper part of the oven is necessary to get the best results. Without the upper heating coil the bread, cake or biscuits will burn on the bottom before they are satisfactorily browned on top. For the lower temperatures this upper coil is unnecessary.

Furthermore, for baking at the higher temperatures, the food and the heating coil must be separated several inches with a baffle between to secure more uniform heating and to prevent burning on the bottom. This arrangement, tho necessary, results in poor heat conductivity between the heating element and the food. Hence, more energy will be required as indicated in the tests in heating water in the oven and on top of the stove. Since in cooking at the boiling point or below the food can be partly immersed in water, there is not the danger of burning as in baking. The baffle over the heating coil can, consequently, be dispensed with and the vessel of food can be placed directly on the heating element. A much better heat conductivity between the food and the heating element will result. Less energy will be required for the first part of the cooking process when the food is being heated from the room temperature to the required cooking temperature.

As the size of an electric oven greatly affects the amount of the losses, an oven should be made as small as is practical for the size of the family that is to use it. For instance, oven No. 1 is uneconomical for a small family as several loaves of bread, cakes or tins of biscuits can be baked in it for the cost of one. For cooking at the lower temperatures the oven can be made smaller than for baking at the high temperatures as there is not the danger of the food burning due to non-uniform heating. For this class of cooking the utensils can

fit snugly into the oven so that the size of the oven can be reduced to a minimum.

The increased popularity of the fireless cooker indicates that people are learning that food can be cooked at temperatures lower than the boiling point of water. The particular temperature of 100°C. (212°F.) has long been the one used for cooking cereals, vegetables, and meats. This is because it is the easiest temperature to maintain at a constant value and not because it necessarily gives the best possible results. The fact that several hours are required for the cooking at lower temperatures is not a disadvantage when the process is automatic and does not require the attention of the housewife. Aside from the question of the quality of the food and the saving in electricity, four hours would probably be the most convenient time to allow for cooking food. The housewife could put in the food for the midday meal immediately after breakfast while the oven was still hot. When it was taken out she could put in the evening meal so that the oven would be used continuously. The preheating loss would thus be reduced to a minimum. During the latter part of the afternoon the housewife would not need to be tied to her kitchen, since all that would be necessary at this time would be to dish up the food and serve it.

The electric light and power companies should be interested in perfecting this method of cooking and in bringing it to the attention of their customers. A combination of the electric oven and the popular fireless cooker would be a very desirable load for the central station. It would be a steady all day load and would not interfere with the peak load even in the winter; as enough heat can be stored in a well-insulated oven to keep the food sufficiently hot for an hour or more after the current is turned off.

The results of the cooking experiments in electric ovens indicate that it is possible to reduce the art of cooking to an exact science. If definite rules of time and temperature were formulated for cooking each article of food, the inexperienced housewife could obtain uniformly good results with the expenditure of a minimum amount of attention and fuel.

The requirements for an electric oven for baking at the higher temperatures are,—minimum heat capacity of the oven, a large heating unit to heat up the oven from room temperature, an automatic device to cut out this heating unit as soon as the oven reaches the desired temperature, smaller heating coils to maintain the temperature at the desired value, a heating unit in the upper part of the oven, a baffle above the lower coils to distribute the heat, as small an oven as is practical for the size of family using it, and from two to four inches of heat insulation.

The requirements of an electric oven for cooking at the lower temperatures are,—from three to four inches of heat insulation, a simple device for automatically controlling the temperature, a large coil for

heating up the food from room temperature, placing the vessels of food directly on the heating units whenever possible, and a size of oven only large enough to contain the utensils to be used.

The author begs to acknowledge his indebtedness to the Misses Stanley, Daniels, and Troxell of the home economics department of the University of Missouri for their many valuable suggestions and for their supervision of the bread, cake, and biscuit experiments; and to Messrs. Atkins, Brinkmeier, Crider and Macon for their assistance in taking readings during the progress of the work.

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HEAT TRANSMISSION THRU BOILER TUBES

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COLUMBIA, MISSOURI

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HEAT TRANSMISSION THRU STEAM BOILER TUBES

INTRODUCTION

The equipment in a steam power plant may be roughly divided into two parts:

(a) The steam generating equipment; the boiler plant.

(b) The steam utilizing equipment; the engines or turbines.

For several years steam engineers have realized that the upper limit of efficiency is being closely approached in the operation of steam engines and turbines. Further material increase in overall efficiency of the plant must be secured thru improvements in the boiler equipment. Many investigators are therefore turning their attention to the study and analysis of boiler plant phenomena, hoping that a clear understanding of the laws which govern the operation of boilers will result in improved methods of designing, building and operating, and lead to higher efficiences.

The processes involved in transferring the heat energy latent in the fuel to the water in the boiler are all somewhat complicated, each one of the several steps involving a number of independent variables. The complete operating cycle is therefore difficult to analyze in all its complications; it seems best to study the different steps separately.

This bulletin is the record of some experiments carried out in an effort to determine the laws controlling the rate at which the heat, carried by the gases passing through a boiler, is tranmitted from the gases to the water in the boiler. The tests to be described were conducted in the laboratories of the Engineering Experiment Station of the University of Missouri. The tests were planned by Mr. E. A. Fessenden in the summer of 1913, and preparations for the tests were begun in September, of that year. The tests proper were started in March, 1914, and continued until April, 1915.

Mr. Fessenden and Mr. Haney together ran every test and took every observation. All computations involved were made twice, first by Mr. Haney, and independently by Mr. Fessenden.

The authors desire to express their appreciation of the valuable assistance rendered by Professor E. R. Hedrick of the department of mathematics, University of Missouri. The formula finally selected as most consistently satisfying all available test data [Eq. (4), p. 6.] and all equations resulting from this formula are to be credited entirely to Professor Hedrick.

Material resulting from the work of other experimenters has been freely used and proper credit in all these cases is given in the body of the bulletin.

THEORIES OF HEAT TRANSFERENCE

The rate of heat transference from the hot gases passing through a tube to water surrounding the tube depends upon the temperature of the gases and the water, and upon the heat insulating resistance which lies between the gases and the water.

The resistance to heat flow in such cases is now supposed to be made up of five parts:

1. The resistance of the metal tube.

2 and 3. The "skin resistance" of the two bounding surfaces of the tube.

4 and 5. Two "film resistances"; one caused by a thin layer of more or less inert and partially cooled gas on the inside of the tube, and the other by a similar layer made up of a mixture of steam bubbles and "superheated" water on the outside of the tube.

Whether such films (4 and 5) actually exist or not is not now known; their use is a convenient mental conception which seems to be borne out by results of experiments. If they do exist, their thickness and resistance can be reduced by a high velocity of gases on the inside of the tube and rapid circulation of the water over the tube surface on the water side. When the gas velocity is low, the film of inert partially cooled gases is relatively thick and the resistance to heat transfer large. As the velocity of the gas increases, this film of inert gas is partially brushed away and made thinner and the "film resistance" correspondingly decreased.

Similarly, if the water circulation is slow, a film of steam bubbles and "superheated" water is formed, whose resistance retards the transfer of heat from the tube to the surrounding water. Rapid water circulation tends to brush the film away and reduce the heat resistance. Experiments have shown that the "film resistance" is not nearly so great on the water side of the tube as on the gas side, because ebullition has a tendency to break the film. Some of these effects have been shown by certain experiments upon surface condensers.*

The heat resistance of the actual metal tube alone is very small in comparison with the total resistance. It is supposed to be of the order of about one one-thousandth of the total resistance.

Little is known of the so-called "skin resistance," and no attempt has been made to separate it from the "film resistance" mentioned above.

The older theories assumed that the rate of heat transfer was directly proportional to the difference in temperature between gases and water, ignoring any effect of velocity in either gases or water.

*Orrok, Transactions A. S. M. E., Vol. 32 (1910) p. 1138 et seq.

That this assumption is faulty is now well understood. The effect of gas and water velocity is apparent when boilers are forced. When larger amounts of gas pass over the heating surfaces, the temperatures of the gases thruout the boiler gas passages are not materially increased while the amount of heat transferred from gas to water may be very much greater.

Sir John Perry, basing his work upon that of Osborne Reynolds, attempted to embody the gas velocity in a formula for heat transfer. This formula can be reduced to the form

$$H = B\ W\ \tau \tag{1}$$

where

H = heat transferred per unit surface, per unit time.
W = weight of gases passing per unit of time.
τ = temperature difference between gas and water.
B = a constant.

The formulae published by the United States Bureau of Mines are similar to Perry's except that a term independent of the weight of gases is introduced into the expression for rate of heat transfer,

$$H = (A + BW)\tau \tag{2}$$

where

A = a constant, and all other quantities are as equation (1).

Mr. William Kent, following Professor Rankine, has advocated a formula based on Blechynden's experiments. This formula assumes that the heat transmitted per unit of time is proportional to the square of the temperature difference, thus,

$$q = \frac{(T - t)^2}{a} \tag{3}$$

where

q = total heat transmitted per unit of surface per unit of time,
T = temperature of gases,
t = temperature of water,
a = a constant ranging from 160 to 200.

It is to be noted that Kent's formula is independent of the gas velocity, except in so far as the volume of gases is dependent upon the temperature.

Failure to check any of these formula by any experimental work which came to the attention of the authors, was the reason for undertaking the series of tests herein described. The results of these tests have led to a new formula which more nearly satisfies all the available experimental results than any formula known to us.

The principal sources of heat resistance are the peculiar state and

the peculiar behavior of the gas and of the water next to the tube, rather than the intrinsic resistance of the tube wall itself. The total resistance is of the order of one thousand times the intrinsic resistance of the tube wall alone.

The nature of this extra resistance is obscure, but it is clear at least that the water immediately adjoining a hot tube would tend to assume an abnormal state, although a film of steam cannot be said to exist about the tube. In any event the water, if it is actually water, that lies against the tube wall constitutes a film of peculiar behavior. The gas inside the tube tends to form a more or less dead film next to the tube wall; the behavior and amount of this action depends upon the speed of the gas as well as upon the physical condition of the tube wall. These facts are well known and are clearly recognized, but their effect has apparently been neglected.

All the phenomena just mentioned evidently depend upon the temperature. Even the speed of the gas depends upon the temperature, since the gas contracts as it cools. The dependence of the other phenomena is too evident to require explanation. It follows that the resistance itself depends upon the temperature, if we mean by resistance that total resistance mentioned above rather than the intrinsic resistance of the metal alone. This furnishes a basis for the assumptions to be made.

In the formulae developed in this bulletin it is assumed that the total resistance changes according to a law which will be found later. The fundamental assumptions may be stated in several different forms. The one originally started with is the assumption that as we proceed down the tube the amount of the heat loss from a small quantity of gas δQ occupying a length δx of the tube, in passing a given point, falls off according to the usual exponential formula for any damping out process; that is, that

$$\textit{loss of heat in } \delta Q = ce^{-mx} \qquad (4)$$

where m and c are constants.

In the light of our present meagre information concerning the resistance due to gas and steam films, this assumption seems at least as reasonable as any of those mentioned heretofore,* but its real justification occurs later, in that the consequences of this assumption seem to agree with experiments. Any assumption must depend for its validity on such an agreement. Since we have worked out the resulting forms, it appears to us to be both reasonable and simple to take as

* It should be noted that the apparently rational idea that the rate of heat transfer is directly proportional to the temperature difference is, after all, really only an assumption that has been accepted for so long that it is regarded as a statement of fact.

our fundamental assumption another statement which is precisely equivalent to the preceding one.

Let us consider the difference $\phi - \phi_w$ between the entropy ϕ of the gas at gas temperature and the entropy ϕ_w which the same gas would have at the temperature of the water. *We shall assume that the decrease $\delta\phi$ in the entropy of the gas in a small section of the tube of length δx is proportional to the entropy difference $\phi - \phi_w$.* It will appear later that this assumption is indeed equivalent to that mentioned above.

Since ϕ_w is a constant, it follows that $\delta\phi_w$ is zero. Hence $\delta\phi$ is equal to $\delta\ (\phi - \phi_w)$, and the fundamental assumption may be written in the form

$$\delta\ (\phi - \phi_w) = -m\ (\phi - \phi_w)\ \delta x \tag{5}$$

where m is a positve constant. We shall use also the well known relations

$$\delta\phi = \delta H/\theta \tag{6}$$
$$H = c_p\,\theta \tag{7}$$
$$\delta\phi = c_p\ (\delta\theta/\theta) \tag{8}$$

where θ is the absolute temperature

H the heat content of unit weight
c_p the specific heat at constant pressure.†

We shall assume that c_p is a constant, though a slight variation is known to exist; and we shall assume that the pressure is the same throughout the tube, though some variation undoubtedly occurs. Variations in c_p and in p are probably of slight effect in comparison with other sources of error, and the known facts would not seem to justify the use of any other definite statement for either.

From (8) we find

$$\phi - \phi_w = c_p \log_e \frac{\theta}{\theta_w} \tag{9}$$

and therefore (5) becomes, in the limit as δx approaches zero,

$$\frac{d \log_e (\theta/\theta_w)}{dx} = -m \log_e (\theta/\theta_w) \tag{10}$$

If we denote $\log_e\ (\theta/\theta_w)$, which is proportional to $\phi - \phi_w$, by s,

† In the mathematical discussion immediately following, the specific heat is treated as a constant for simplicity, though it is really a variable. In the curves for the tests discussed later variability of the specific heat was taken into account, using the values on p. 44.

we have

$$\frac{ds}{dx} = -ms \tag{11}$$

and

$$\frac{ds}{s} = -m dx$$

whence by integration

$$\log_e s = -mx + \kappa \text{ or } s = ke^{-mx} \tag{12}$$

where κ and k are constants, and where $\kappa = \log_e k$. If $x = 0$, s has the value $s_0 = \log_e (\theta_0/\theta_w)$, where θ_0 is the absolute temperature of the gas as it enters the tube. Hence, inserting these values, $k = s_0$ or $\kappa = \log_e s_0$; and (12) may be written in the form

$$\log_e (s/s_0) = -mx \text{ or } s = s_0 e^{-mx} \tag{13}$$

In terms of θ these formulae are

$$\log_e (\theta/\theta_w) = \log_e (\theta_0/\theta_w) e^{-mx} \text{ or } \theta/\theta_w = (\theta_0/\theta_w)^{e^{-mx}} \tag{14}$$

For comparison with numerical data is it desirable to have these formulae expressed in common logarithms. Remembering that

$$\log_{10} N = \log_e N \times \log_{10} e$$

we may write the formula (14) in the form

$$\log_{10} (\theta/\theta_w) = \log_{10} (\theta_0/\theta_w) e^{-mx} \tag{15}$$

Let us set

$$R = \log_{10} (\theta/\theta_w) \text{ and } R_0 = \log_{10} (\theta_0/\theta_w) \tag{16}$$

so that R is proportional to s used above, or to $\phi - \phi_w$. Using this notation, and taking common logarithms again, we have

$$\log_{10} R = K - Mx \tag{17}$$

where

$$K = \log_{10} R_0 = \log_{10} [\log_{10} (\theta_0/\theta_w)], \text{ and } M = m \log_{10} e$$

In the numerical computations of this paper the quantities θ, θ/θ_w, R, and $\log_{10} R$ are tabulated in that order. Denoting the last of these by Θ:

$$\Theta = \log_{10} R = \log_{10} [\log_{10} (\theta/\theta_w)] \tag{18}$$

and we have

$$\Theta = K - Mx \tag{19}$$

where K and M are constants defined above.

In order to check any set of numerical data with this formula, all

that is necessary is to calculate Θ by (18) and then to plot the values of Θ against the corresponding values of x; the resulting figure should be a straight line.

To convert the preceding equations into forms which can be compared with the measurements of the tests made by the authors let us return to equation (9) and substitute in it from (7) where H means the heat content reckoned from $H=0$ at $\theta=0$. We have then

$$\phi - \phi_w = c_p \log_e (H/H_w) \tag{20}$$

and the further reduction is precisely similar to that above, with the ratio H/H_w in place of the ratio θ/θ_w. Hence we have as in (14)

$$\log\ (H/H_w) = \log_e (H_0/H_w) e^{-mx}, \text{ or } H/H_w = \left(H_0/H_w\right)^{e^{-mx}} \tag{21}$$

and also, as in (17)

$$\log_{10} [\log_{10} (H/H_w)] = K - Mx \tag{22}$$

where

$$K = \log_{10} [\log_{10} (H_0/H_w)], \text{ and } M = m \log_{10} e \tag{23}$$

As an example of the correspondence between the theory outlined above and the actual test results, reference is made to the data and computation sheet for test I 12, given on pages 38 to 40.

The rate of drop in temperature along the tube is expressible readily on carrying out the indicated differentiation in (10); this gives (see note below)

$$d\theta/dx = -m\theta \log_e (\theta/\theta_w) \tag{24}$$

or, by (14)

$$d\theta/dx = -MR_0\theta e^{-mx} \tag{25}$$

Note. The derivation of eqs. (24) and (25) from (10) and (14) is as follows:

Eq. (10) is $$\frac{d(\log_e \theta/\theta_w)}{dx} = -m \log_e \theta/\theta_w.$$

$$d(\log_e \theta/\theta_w) = -m \log_e \theta/\theta_w\, dx,$$

$$d\,[\log_e\theta - \log_e\theta_w] = -m \log_e \frac{\theta}{\theta_w} dx;$$

but $\log_e\theta_w$ is a constant, $\therefore\ d[\log_e\theta_w] = 0$;

$$\therefore d\,[\log_e\theta] = -m \log_e \frac{\theta}{\theta_w} dx.$$

Since the volume of a given weight of gas is proportional to its absolute temperature θ, the weight of the amount of gas δQ in a section of length δx is inversely proportional to θ, and we have

$$loss\ of\ heat\ in\ \delta Q = + ce^{-mx}$$

which agrees with (4) and shows the equivalence of the fundamental assumptions mentioned at the beginning.

It is easy to express the efficiency in general as a function of x and M. For if the efficiency E of a tube of length x be defined to be the heat absorbed in that length of tube divided by the total heat content of the gases reckoned above water temperature, we have

$$(1-E) = \frac{H - H_w}{H_0 - H_w} = \frac{H_w}{H_0 - H_w}\left[\left(H_0/H_w\right)^{e^{-mx}} - 1\right] \qquad (26)$$

where

$$m = M \log_e 10 = 2.3026 \times M$$

$$\text{but } d\,[\log_e \Theta] = \frac{\log_e e}{\theta}\, d\theta;\ \text{and } \log_e e = 1$$

$$\therefore d\,[\log_e \theta] = \frac{d\theta}{\theta} = -m \log_e \frac{\theta}{\theta_w}\, dx$$

$$d\theta = -\theta\, m \log_e \frac{\theta}{\theta_w}\, dx, \text{ or } \frac{d\theta}{dx} = m\,\theta \log_e \frac{\theta}{\theta_w} \qquad (24)$$

$$\text{Eq. (14) is} \quad \log_e \frac{\theta}{\theta_w} = \log_e \frac{\theta}{\theta_w}\, e^{-mx}$$

$$\text{but} \quad R_0 = \log_{10} \frac{\theta_0}{\theta_w},\ \text{so that } \log_e \frac{\theta_0}{\theta_w} = 2.3026\, R_0$$

$$\text{also } M = 2.3026 m \text{ or } m = \frac{M}{2.3026}$$

$$\therefore m \log_e \frac{\theta}{\theta_w} = \frac{M}{2.3026} \times 2.3026\, R_0 = M R_0$$

$$\therefore \frac{d\theta}{dx} = -m\,\theta \log_e \frac{\theta}{\theta_w} = MR_0 \theta e^{-mx} \qquad (25)$$

INADEQUACY OF FORMULAE IN CURRENT USE

It has already been stated that the reason for entering upon the experiments and computations herein described was the inability to check the results of published experiments by the formulae in current use. The examples shown below are fair samples of the results of all tests which have come into our hands where sufficient data has been published to permit the necessary computations.

Perry's Formula. The original form in which Sir John Perry expressed the formula which bears his name is adapted from a paper by Professor Osbourne Reynolds, published in the *Philosophical Transactions* in 1883. As stated by Perry in "The Steam Engine," 1909, p. 588, the formula is an expression for the heat transmitted through a gaseous film,

$$H = c' w v (t - t') \tag{27}$$

in which

$H =$ the heat energy transmitted per second, per unit area,
$w =$ the weight of a unit volume of the gases,
$v =$ the average axial velocity of the gases,
$c' =$ a constant.
$(t - t') =$ the difference in temperature between the hot and cold surface of the gaseous film.

In adapting this formula for the heat transmitted from gases to water in a boiler, Perry, (l. c. p. 591) uses the difference in temperature between gases and water, which we have called τ, in place of $(t - t')$.

If V is the volume of gases flowing per unit of time, the weight of these gases is

$$W = Vw$$

The velocity is

$$v = \frac{V}{a}$$

where a is the cross-sectional area of the gas passages. It follows that

$$w v = \frac{W}{V} \times \frac{V}{a} = \frac{W}{a} \tag{28}$$

If τ is substituted for $(t - t')$, to conform with Perry's procedure, and

B for $\frac{c'}{a}$, equation (27) becomes equation (1) as previously stated,

$$H = BW\tau \tag{1}$$

In traversing a small element of surface, dS, the heat transmitted is

$$HdS = BW\tau dS \tag{29}$$

At the same time the gas temperature must fall a small amount, dt, as the gases give up heat. Since the water temperature is constant, $d\tau$ is equal to dt and can be used in its place. The heat lost by the gases due to the decrease in temperature $d\tau$ must be equal to the heat transmitted, so that

$$-WC_p d\tau = BW\tau dS \tag{30}$$

or

$$\frac{d\tau}{\tau} = -\frac{B}{C_p}\, dS \tag{31}$$

Integrating between τ_f and τ_x, and S_o ($=0$) and S_x gives

$$\log \frac{\tau_x}{\tau_f} = -\frac{B}{C_p} S_x \tag{32}$$

or

$$\frac{\tau_x}{\tau_f} = e^{-\frac{B}{C_p} S_x} \tag{33}$$

where e is the Naperian base, 2.71828, and S_x is the total surface passed over up to the distance x from the fire box end of the tube. If the tube diameter is d (in feet),

$$S_x = \frac{\pi d^2}{4} x$$

The quantity $\frac{B}{C_p} S_x = \frac{\pi B d^2}{4C_p} x$ may be written as px if it is assumed that the specific heat is constant, and equation (33) becomes

$$\frac{\tau_x}{\tau_f} = e^{-px} \tag{34}$$

The efficiency up to the point x is

$$E = \frac{\tau_f - \tau_x}{\tau_f} = 1 - \frac{\tau_x}{\tau_f} = 1 - e^{-px} \tag{35}$$

which is the same as the equation given by Perry (l. c. 591) except that we have here used x to designate length of tube from the fire box end where Perry uses l, and we have replaced Perry's constant term c/d by p.

Equation (35) may be rewritten as

$$1-E=e^{-px} \tag{36}$$

and, taking logarithms of both sides,

$$\log_{10}(1-E)=-Px \tag{37}$$

where

$$P=p\log_{10}e$$

Equation (34) may be written in the form

$$\tau_x=\tau_f\, e^{-px} \tag{38}$$

from which

$$\log_e \tau^x=\log_e \tau_f-px \tag{39}$$

Since τ_f is a constant, $\log \tau_x$ plotted against x should be a straight line. It is more convenient to use logarithms to the base 10, so that equation (39) becomes

$$\log_{10}\tau_x=\log_{10}\tau_f-Px \tag{40}$$

where, as before,

$$P=p\log_{10}e$$

Perry* gives the actual values of E, according to his own computations for the classic French experiments on a locomotive boiler. These values, and the corresponding values of $1-E$ and $\log_{10}(1-E)$ which we computed in order to check with Perry's formula (37), are given in table I.

In the last row of each set of values are given the computed values of P; these are found by dividing the differences between successive values of $\log_{10}(1-E)$ by the corresponding differences in x.†

A different set of values P can also be obtained by direct substitution in equation (37)

$$-P=\frac{\log_{10}(1-E)}{x} \tag{41}$$

These values are given below for the same points as in Table 1:

x in feet	0	3	6	9	12
P (coal tests)	....	0.0496	0.0418	0.0359	0.0314
P (coke tests)	....	0.0588	0.0503	0.0436	0.0387

*Perry, The Steam Engine, 1909, p. 432.

†$\log_{10}(1-E)=-Px$, or for particular values,

$$\log_{10}(1-E_1)=-Px_1 \quad \text{(a)}$$
$$\log_{10}(1-E_2)=-Px_2 \quad \text{(b)}$$
etc.

Substracting (b) from (a)

$$\log_{10}(1-E_1)-\log_{10}(1-E_2)=-Px_1+Px_2=-P(x_1-x_2)$$

$$\therefore P=\frac{\log_{10}(1-E_1)-\log_{10}(1-E_2)}{-(x_1-x_2)}=\frac{\log_{10}(1-E_1)-\log_{10}(1-E_2)}{x_2-x_1}$$

The authors feel that the method of differences is preferable to the second method, since the second method counts from the fire-box end of the tube for each computation, and gives excessive weight to that particular portion of the tube. The first method takes each section of the tube separately and the value of P found applies to that

TABLE I. PERRY'S VALUES FOR E, FRENCH EXPERIMENTS

Coal	x in feet	0	3	6	9	12
	E	0.000	0.290	0.439	0.525	0.580
	$1-E$	1.000	0.710	0.561	0.475	0.420
	$\log_{10}(1-E)$	0.000	9.8513	9.7490	9.6767	9.6232
	P	....	0.0496	0.0341	0.0241	0.0178
Coke	E	0.000	0.334	0.501	0.595	0.658
	$1-E$	1.000	0.666	0.499	0.405	0.342
	$\log(1-E)$	0.000	9.8235	9.6981	9.6075	9.5340
	P	....	0.0588	0.0418	0.0305	0.0212

particular section of the tube. The second method gives a value of P for length of the tube from the firebox end to the end of the section considered.

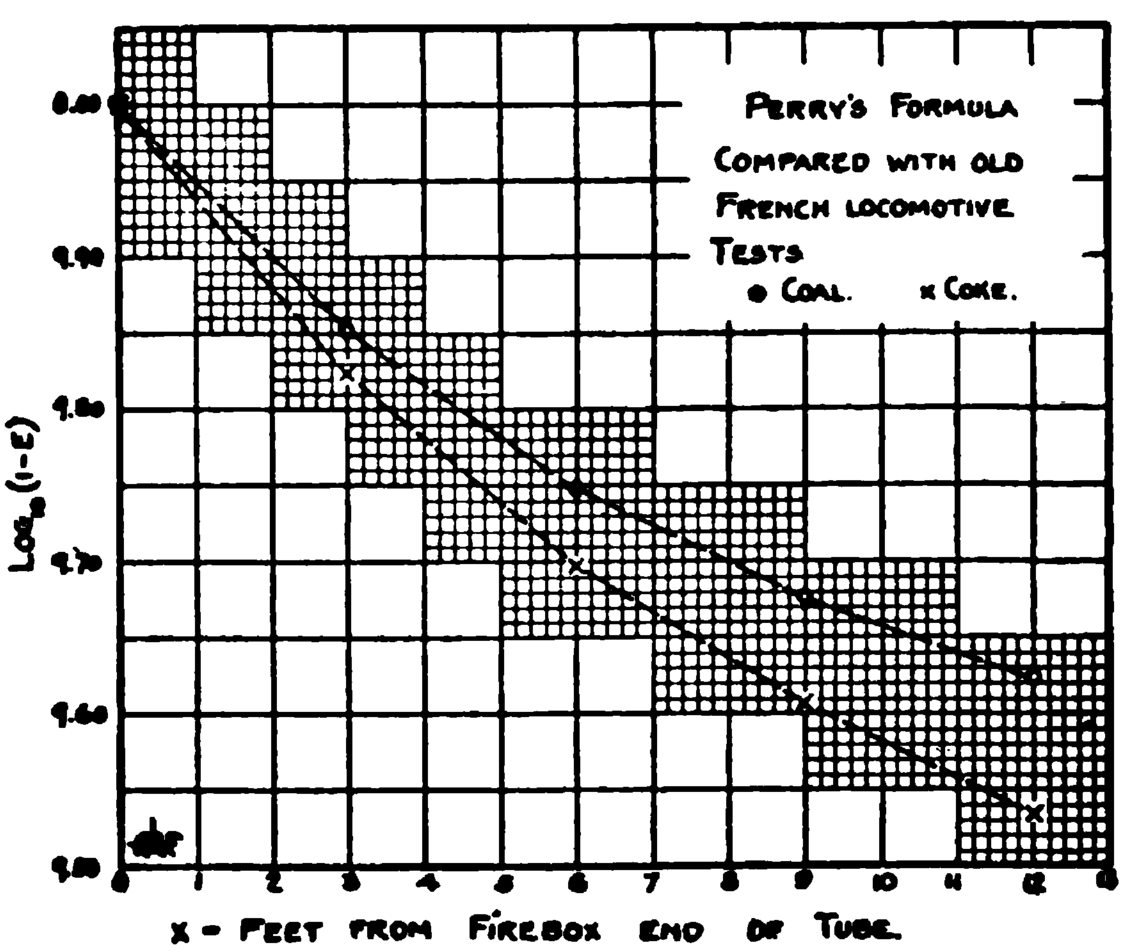

Figure 1.

If P were constant, as it should be if Perry's formula holds, the two methods would of course give identical results. It will be seen, however, that the values of P are not constant within any reasonable limits, for either set of experiments, or for either method of computing.

Instead, the values of P diminish steadily as x increases, and the last value is only about one-third of the first value.

Figure 1 shows clearly the same discrepancy. In it, the values of $\log_{10}(1-E)$ are plotted against the values of x. If Perry's formula (37) held, the resulting figure should be a straight line, which it clearly is not. Unfortunately, the data given in these experiments are not sufficient to check against the formulæ developed from our experiments.

Several sets of data giving direct temperature measurements in a locomotive boiler tube at every foot of its length were kindly furnished us by Chas. D. Young, Engineer of Tests for the Pennsylvania Railroad. These are given in tables 2, 3 and 4, and the figures, both for comparison with our formulæ (14)-(19) and with Perry's formula (40) are plotted in figures 2, 3 and 4.

These figures speak for themselves. Particularly in view of the great difficulty experienced in making such measurements, the agreement with formulæ (14)-(19) is remarkably good, and any variations from a straight line are apparently at random rather than consistent. On the other hand, the points marked by small crosses, for

TABLE 2. COMPARISON OF PERRY'S, YOUNG'S AND AUTHORS' VALUES

Young's values from Test No. 377, Penna. R. R., Locomotive.

x in ft.	τ_x	$\log_{10}\tau_x$	$\theta=\tau_x+844$	$\log\theta$	$R=\log(\theta/\theta_{10})$	$\Theta=\log R$
0	1022	3.0008	1846	3.26623	0.33989	9.5313
1	822	2.9149	1666	3.22167	0.29533	9.4703
2	762	2.8820	1606	3.20575	0.27941	9.4462
3	667	2.8241	1501	3.17638	0.24994	9.3978
4	527	2.7218	1371	3.13704	0.21070	9.3237
5	482	2.6830	1326	3.12254	0.19620	9.2927
6	417	2.6201	1261	3.10072	0.17438	9.2416
7	392	2.5933	1236	3.09202	0.16568	9.2193
8	347	2.5403	1191	3.07591	0.14957	9.1749
9	337	2.5276	1181	3.07225	0.14591	9.1641
10	297	2.4728	1141	3.05729	0.13095	9.1173
11	242	2.3838	1086	3.03583	0.10949	9.0394
12	227	2.2560	1071	3.02979	0.10345	9.0149
13	177	2.2480	1021	3.00903	0.07269	8.9175
14	167	2.2227	1011	3.00475	0.07841	8.8944
15	162	2.2095	1006	3.00260	0.07626	8.8823

$\theta_{10}=844$ $\qquad\log\theta_{10}=2.92634$

comparison with Perry's formula, seem to show a consistent tendency to be low in the middle and high on both ends.

Perhaps the chief source of error in taking such measurements is the radiation of heat from the thermal couple itself to the relatively cold surface of the surrounding tube wall. The error due to this cause is not inconsiderable; it may run as high as 100 deg. fahr. and it is

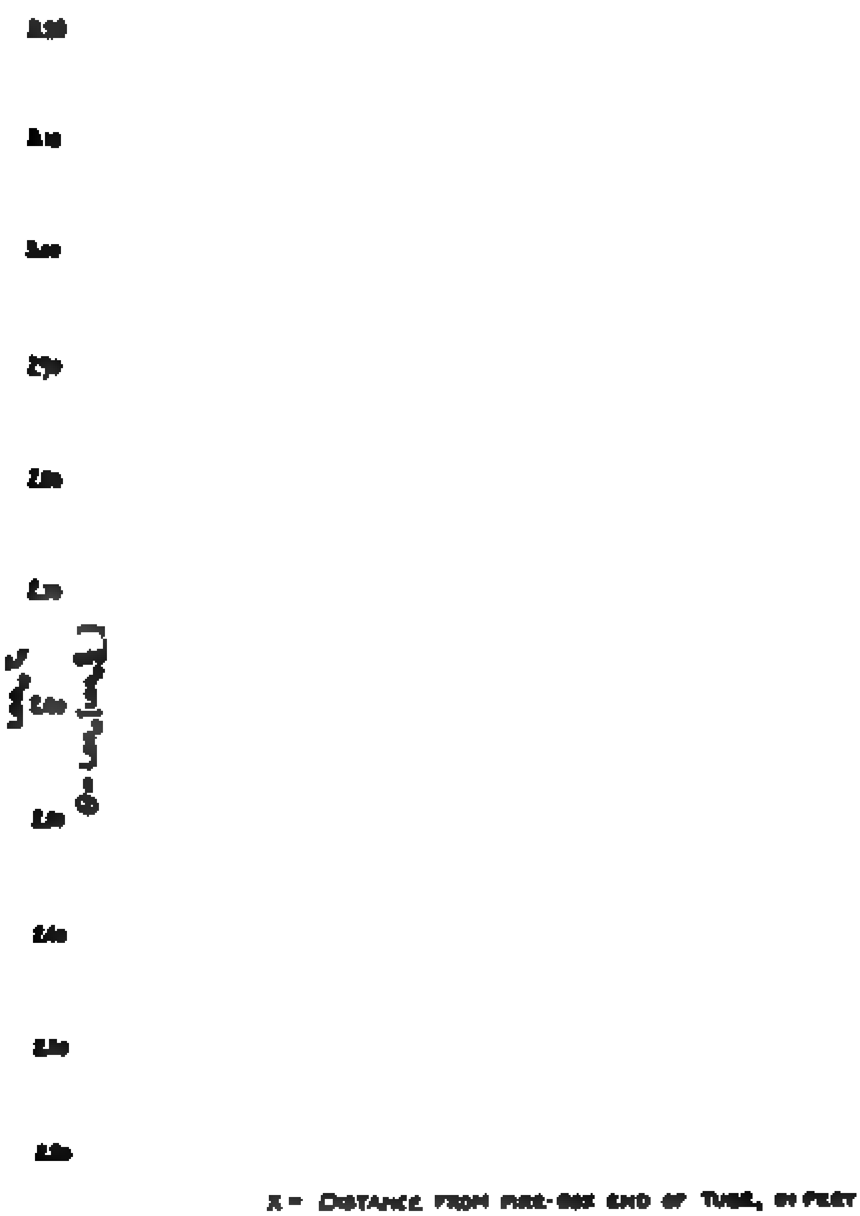

Figure 8.

difficult to estimate because it depends on a number of uncertain factors. It is quite probable that radiation errors from the thermocouples are responsible for the erratic character of the results shown in figures 2, 3 and 4.

It should be remarked also that the very first and the very last of the measurements may be relatively high, since the radiation from a thermal couple at the end of a tube is effective only through

half the spherical angle about the point, whereas a couple located well within the tube radiates to the cold iron through practically the entire spherical angle. Evidences that this effect does exist are present in all these diagrams. It is certainly reasonable to give rather less weight to these two extreme points, but the next to the last on either end should show only random errors.

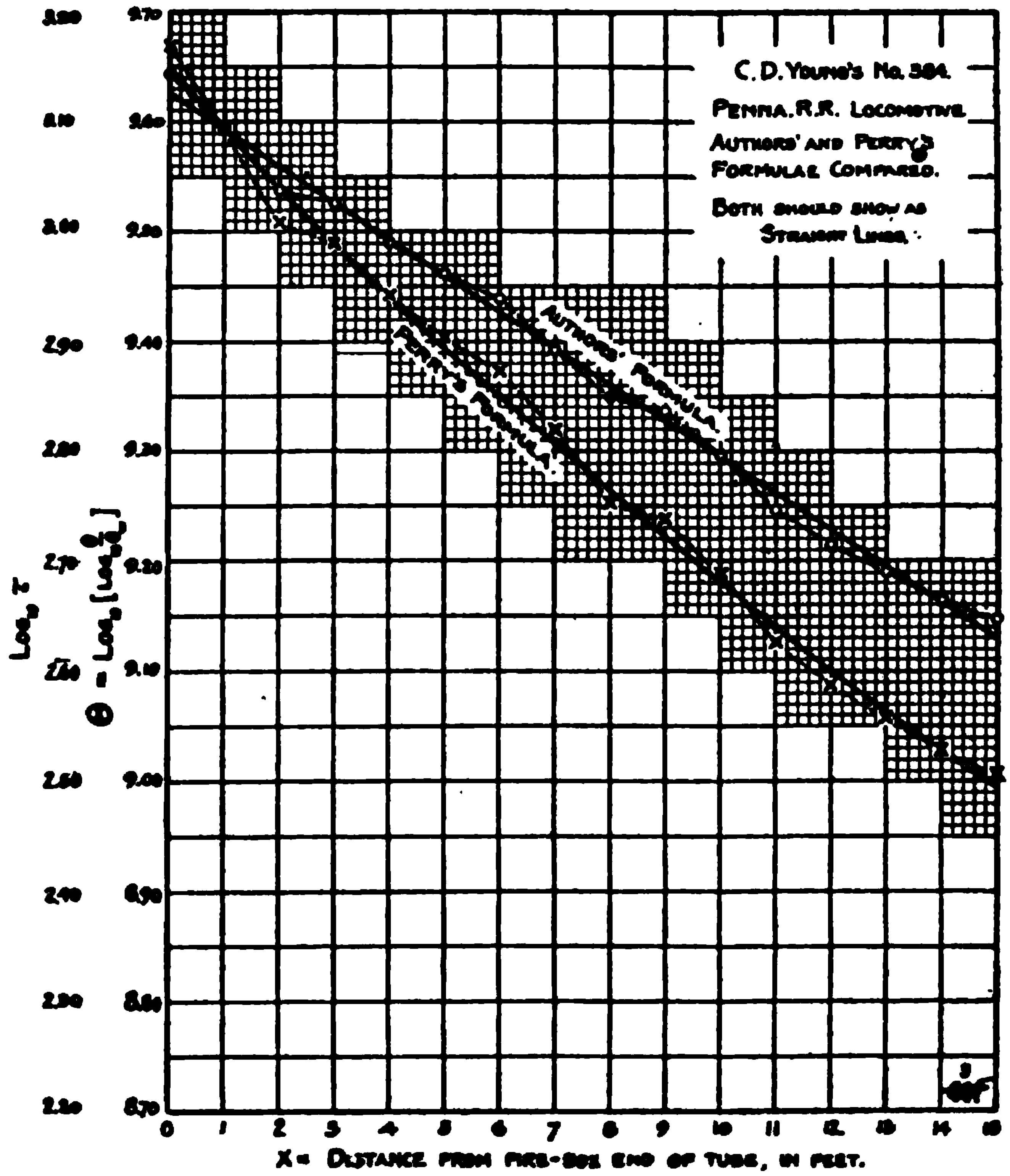

Figure 3.

Points obtained by Perry's formula (40) for one of the recently completed Babcock and Wilcox Company's tests* are shown by small crosses in figure 5, corresponding points by the formula (19) by small circles. The tendency for the Perry points to be low in the middle is again apparent.

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*These tests are further discussed on pp. 69-73, and tables giving the data here plotted are given on page 74.

Perry's formula and that of the authors are further compared in some results of a few of the experiments which form the basis of this bulletin in figures 6, 7 and 8. In the computations for these figures it is assumed that

$$\frac{H - H_w}{H_0 - H_w} = \frac{\tau_x}{\tau_f} \tag{41}$$

(This is equivalent to assuming constant specific heat for the gases in order to avoid laborious computations.) Equation (40) states Perry's formula as

$$\log_{10} \tau_x = \log_{10} \tau_f - Px \tag{42}$$

which may be written

$$\log_{10} \frac{\tau_x}{\tau_f} = Px \tag{43}$$

or, using the substitution indicated above,

$$\log_{10} \frac{H - H_w}{H_0 - H_w} = -Px \tag{44}$$

which is the equation of a straight line.

TABLE 3. COMPARISON OF PERRY'S, YOUNG'S AND AUTHORS' VALUES

Young's values from Test No. 384, Penna. R. R., Locomotive.

in ft.	τ_x	$\log_{10}\tau_x$	$\theta=\tau_x+844$	$\log\theta$	$R=\log(\theta/\theta_w)$	$\Theta=\log R$
0	1477	3.16938	2321	3.36568	0.43934	9.6428
1	1242	3.09412	-2086	3.31031	0.39297	9.5943
2	1022	3.00945	1866	3.27091	0.34457	9.5373
3	977	2.98989	1821	3.26031	0.33397	9.5237
4	877	2.94300	1721	3.23578	0.30944	9.4906
5	802	2.90417	1646	3.21643	0.29009	9.4625
6	747	2.87332	1591	3.20167	0.27533	9.4398
7	647	2.82090	1491	3.17348	0.24714	9.3929
8	567	2.7536	1411	3.14953	0.22319	9.3487
9	547	2.7380	1391	3.14333	0.21699	9.3364
10	487	2.6875	1331	3.12418	0.19784	9.2963
11	422	2.6253	1266	3.10243	0.17609	9.2457
12	387	2.5877	1231	3.09026	0.16392	9.2146
13	362	2.5587	1206	3.08135	0.15501	9.1903
14	337	2.5276	1181	3.07225	0.14591	9.1641
15	322	2.5079	1166	3.06670	0.14036	9.1472

$\theta_w = 844$ $\log\theta_w = 2.92634$

Values of $\log_{10}\dfrac{H-H_w}{H_0-H_w}$ from several of our experiments for checking Perry's equation in the form (44) and of Θ for the authors' equations (14) to (19) are plotted against x in figures 6, 7 and 8. The points for Perry's formula are marked, as before, by small crosses, those for equation (19) by small circles. It will be noticed that for the values by Perry's formula, there exists again the consistent tendency to be low in the middle. Thus, even if the first point (which

TABLE 4. COMPARISON OF PERRY'S, YOUNG'S AND AUTHORS' VALUES

Young's values from Test No. 378, Penna. R. R., Locomotive.

x in ft.	τ_x	$\log_{10}\tau_x$	$\theta=\tau_x+846$	$\log\theta$	$R=\log(\theta/\theta_w)$	$\Theta=\log R$
0	1015	3.0064	1861	3.26975	0.34238	9.5345
1	975	2.9890	1821	3.26031	0.33294	9.5224
2	875	2.9520	1721	3.23578	0.30841	9.4891
3	795	2.9004	1641	3.21511	0.38774	9.4590
4	700	2.8451	1546	3.18921	0.26184	9.4180
5	595	2.7745	1441	2.15866	0.23129	9.3642
6	500	2.6990	1346	3.12905	0.20168	9.3047
7	495	2.6946	1341	3.12743	0.20006	9.3011
8	450	2.6532	1296	3.11261	0.18524	9.2676
9	395	2.5966	1241	3.09377	0.16640	9.2211
10	355	2.5502	1201	3.07954	0.15217	9.1823
11	335	2.5250	1181	3.07225	0.14488	9.1610
12	295	2.4698	1141	3.05729	0.12992	9.1137
13	255	2.4065	1101	3.04179	0.11442	9.0585
14	235	2.3711	1081	3.03383	0.10646	9.0271
15	215	2.3324	1061	3.02572	0.09835	8.9928

$\theta_w = 846$ $\log\theta_w = 2.92737$

may be high on account of radiation from the furnace) and the last point be omitted, the points lie consistently below a line joining the new extreme points. Or again, if a line is laid through the first few points, so as to predict the values of the later ones according to equation (40), the actual points lie above it, and an analogous effect occurs if a line is passed through several of the last points. An important feature is that these effects occur in all the figures.

The agreement of the actual points marked by small circles with a fair straight line indicates that formula (19) more nearly represents actual conditions than Perry's equation. There is at least no consistent tendency for variation from the straight line in any single particular manner. We have plotted in all about forty such runs.

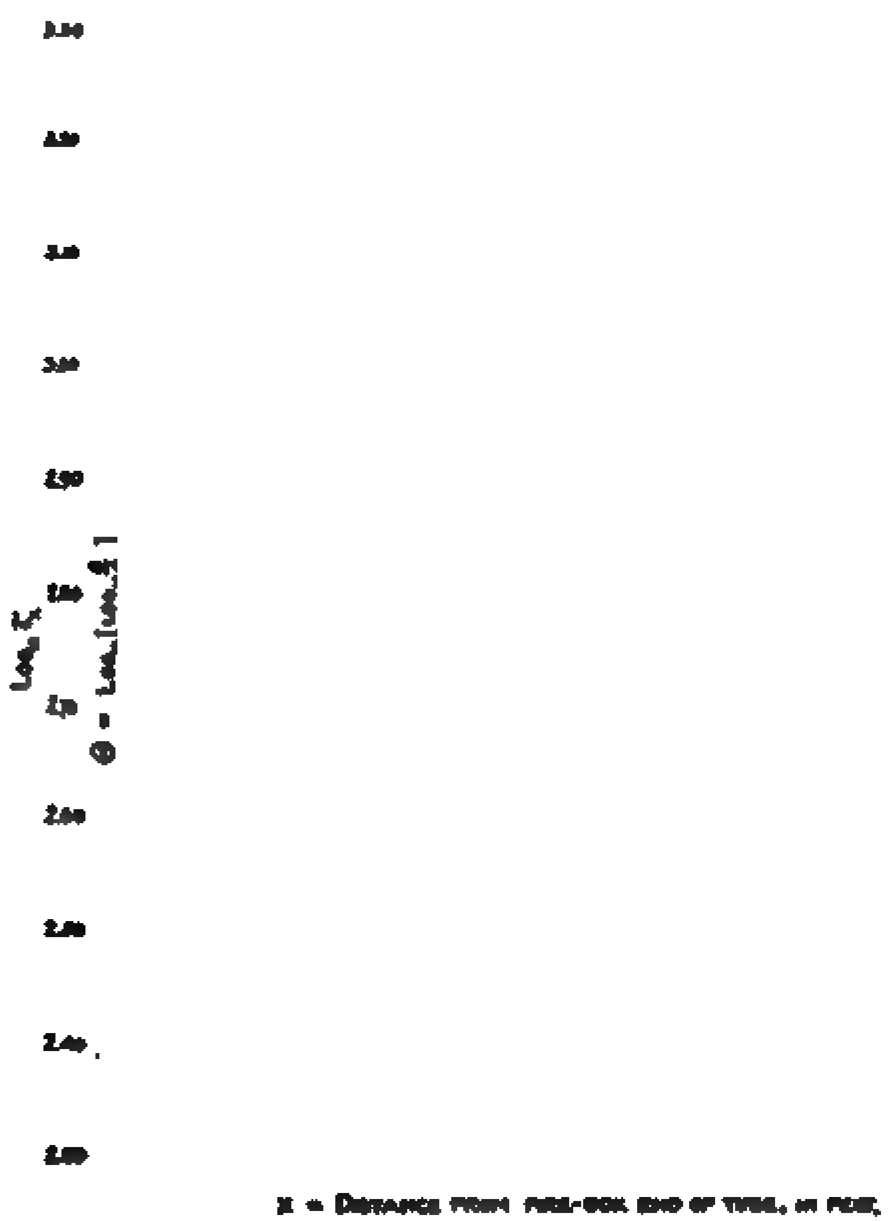

Figure 4.

The agreement is in all cases at least as good as that shown in these figures, these particular runs having been chosen purposely entirely at random.

Bureau of Mines Formula. The original form of the Reynolds-Perry equation used by the Bureau of Mines* is

*Bulletin 18, U. S. Bureau of Mines, p. 114.

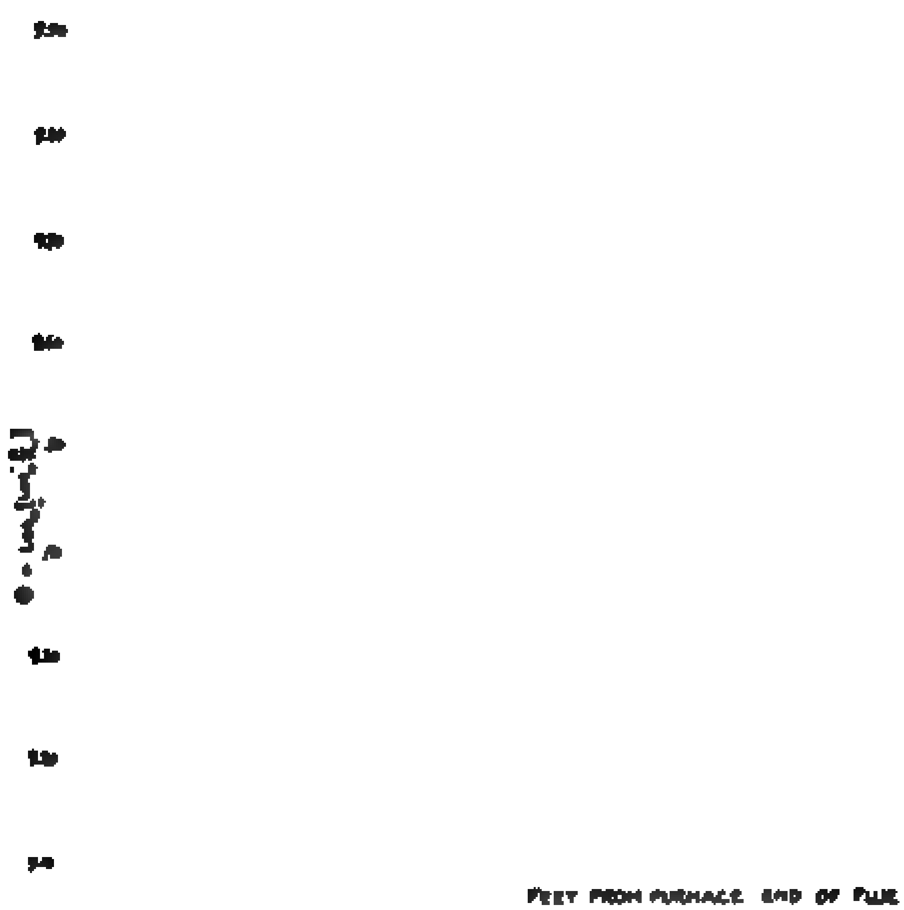

Figure 5.

$$H = A\,(T - t) + B\,(T - t)\,qv. \tag{45}$$

Where

H = heat transferred per unit surface, per unit time.

T = temperature of hot side of tube, assumed to be sensibly the same as the temperature of the gases.

t = temperature of the wet side of the tube, assumed to be sensibly the same as that of the boiler water.

q = density of the gas.

v = velocity of the gases.

A and B = constants depending on the nature of the gas.

This equation we prefer to write in the form

$$H = (A + Bqv)\,(T - t) \tag{46}$$

The product qv is proportional to the weight W of the gases passing per unit of time. Hence, substituting W for qv and τ for $(T - t)$ gives the formula as stated in equation (2)

$$H = (A + BW)\,\tau \tag{2}$$

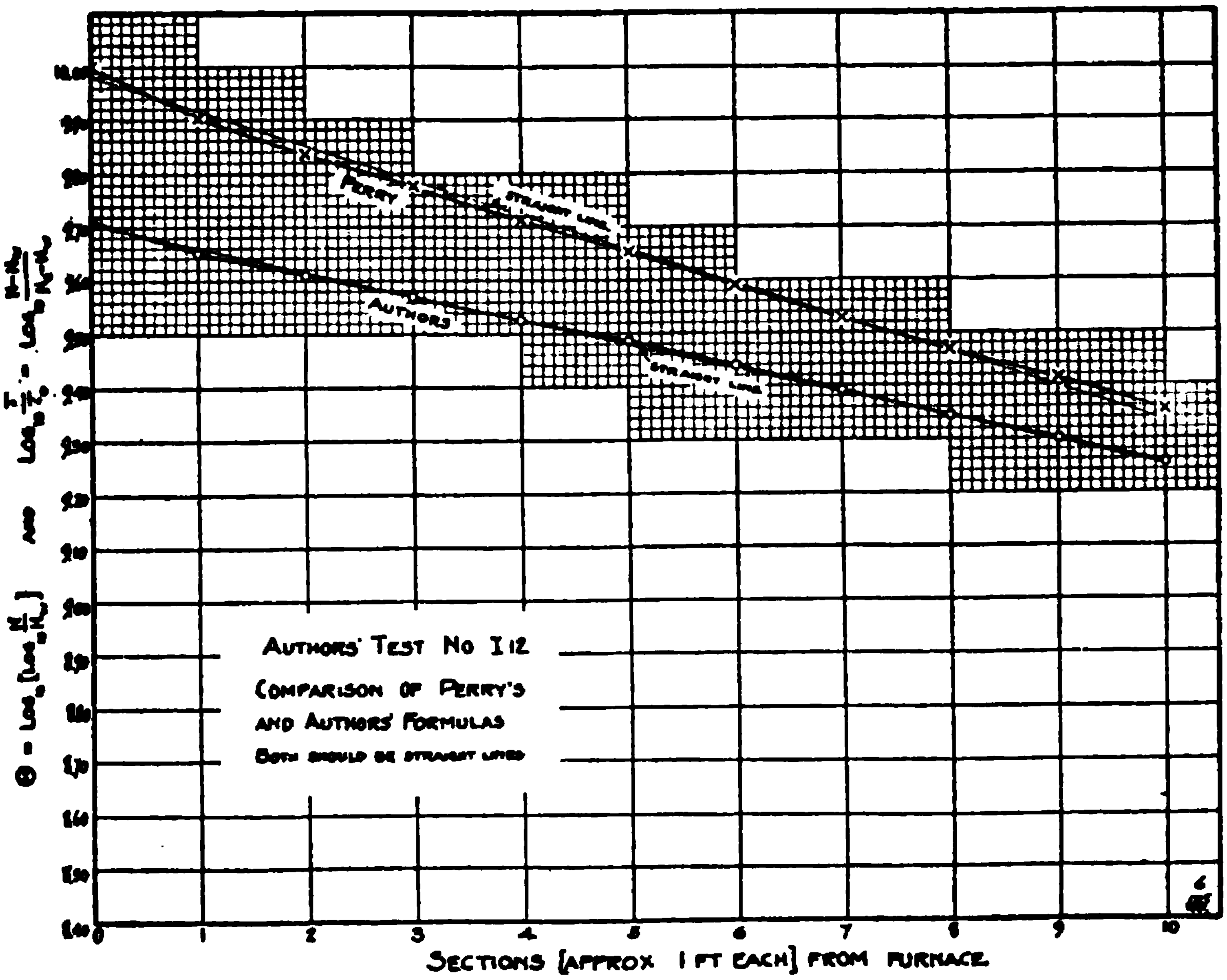

Figure 6.

Many illustrations of the inadequacy of Perry's formula have been given. Each one of these may also be taken as an illustration of an exactly equivalent inadequacy in the Bureau of Mines formula. The truth of the statement is apparent when it is realized that for *any single experiment* the weight of gases passing in a unit of time is the same for every point of the tube, and the only variable in equation (2) is the temperature difference τ. This means that at any point in the tube the heat transfer is simply directly proportional to the temperature difference. Perry's equation (1) considered for *any single experiment* gives exactly the same result. Thus, since all of the illustrations given are for single experiments, *for the purpose of determining the change in heat content in the gases throughout the tube*, the Bureau of Mines formula and Perry's formula are exact equivalents.

The Bureau of Mines formula is probably superior to Perry's for comparing the rate of heat transfer in *different* experiments. Possibly an equation of the form

$$H = (A + BW)\,\tau \tag{2}$$

can be used for both purposes if it is admitted that the quantities A and B are not constants, but variables. Later in this bulletin we have attempted to indicate values for A and B which will satisfy the ex-

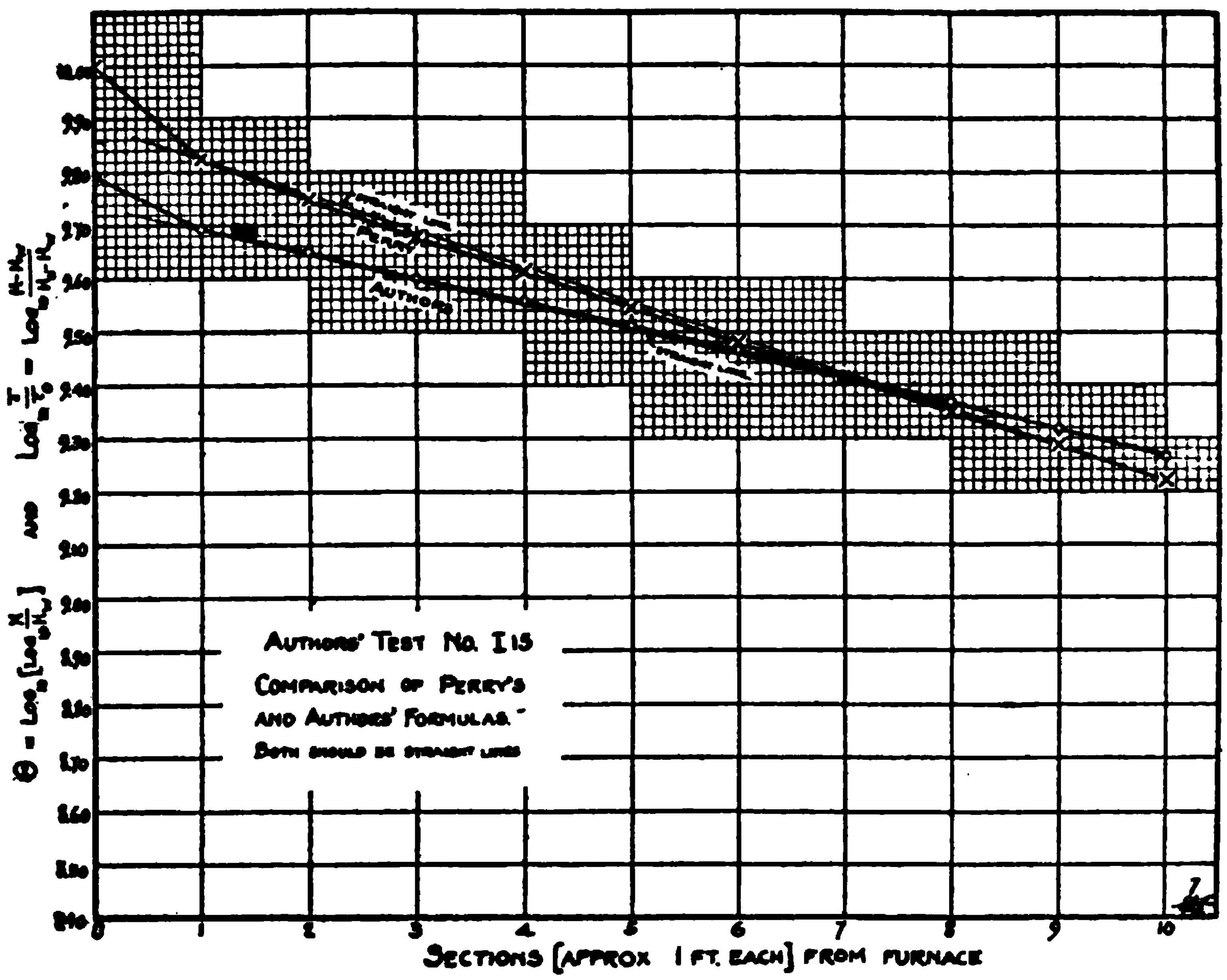

Figure 7.

periments fairly well. It should be noted that no values for A and B are given in the Bureau of Mines Bulletin 18, in which formula (45) is advocated.

Kent's Formula. The only other formula which is in common use is the one adapted from Rankine by Mr. William Kent. This has been given as equation (3) p. 7.

$$q=\frac{(T-t)^2}{a} \qquad (3)$$

Transformed into the notation which has been used for the other computations in the bulletin, this equation becomes

$$H=\frac{\tau^2}{a} \qquad (47)$$

where

$H=$ the heat transmitted per unit of surface, per unit of time.
$\tau=$ temperature difference between gases and water.
$a=$ a constant.

The heat transmitted per unit of time through a surface dS is then

$$HdS=\frac{\tau^2}{a}\,dS \qquad (48)$$

But the heat transmitted must also be equal to the heat lost by the gases, or,

$$HdS = -WC_p dt \tag{49}$$

Since the water temperature is constant, $d\tau = dt$, so that (49) may be written

$$HdS = -WC_p d\tau \tag{50}$$

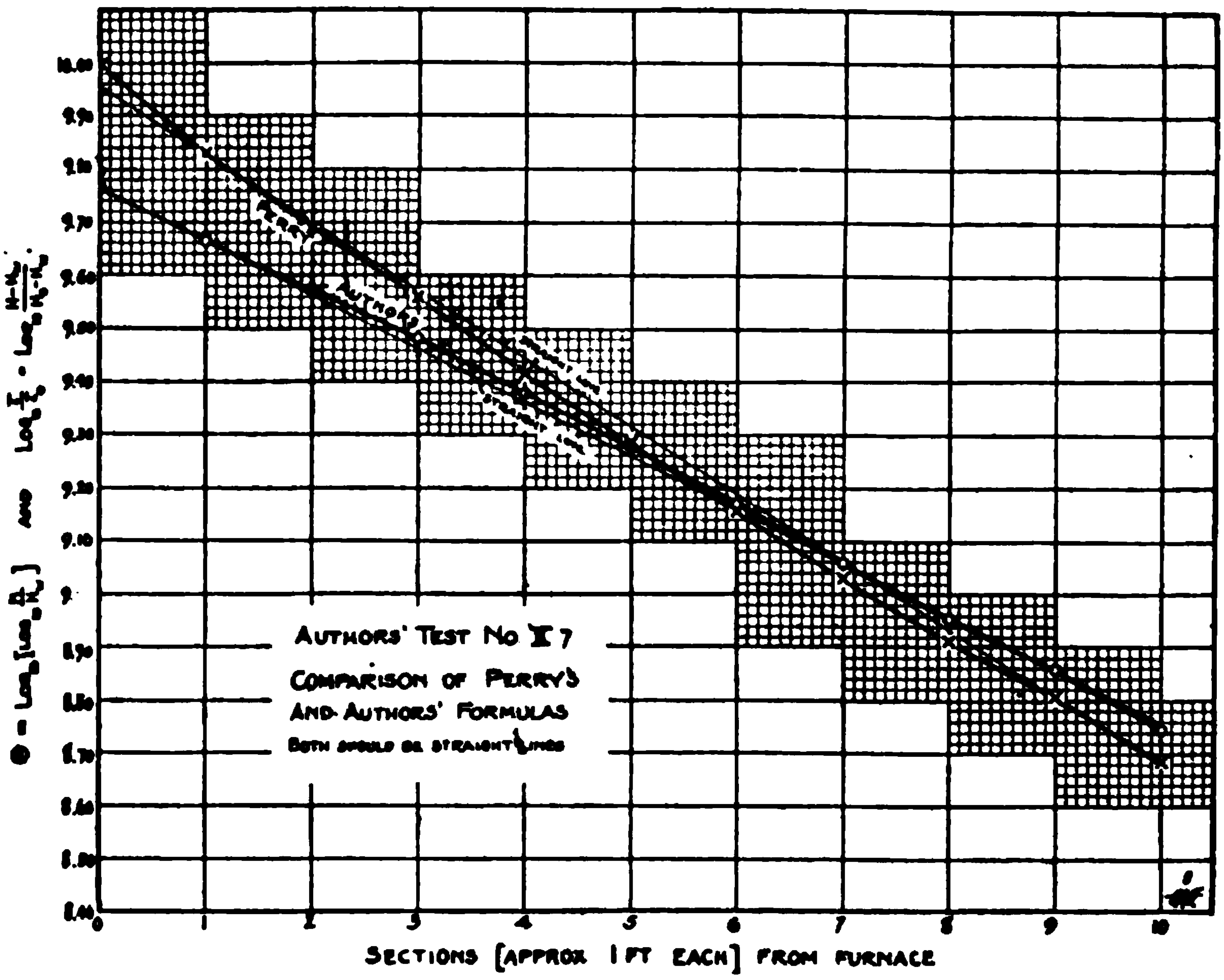

Figure 8.

Combining (48) and (50)

$$\frac{\tau^2}{a} dS = -WC_p d\tau \tag{51}$$

or

$$\frac{d\tau}{\tau^2} = -\frac{dS}{aWC_p} \tag{52}$$

Integrating between τ_f and τ_x, and $S_0 = 0$ and S_x, gives

$$\frac{1}{\tau_f} - \frac{1}{\tau_x} = -\frac{S_x}{aWC_p} \tag{53}$$

Substituting K for $\frac{1}{aWC_p}$

$$\frac{1}{\tau_f} - \frac{1}{\tau_s} = -KS_s \tag{54}$$

Equation (61) may be used for computing τ_s, since

$$\frac{1}{\tau_s} = KS_s + \frac{1}{\tau_f} \tag{55}$$

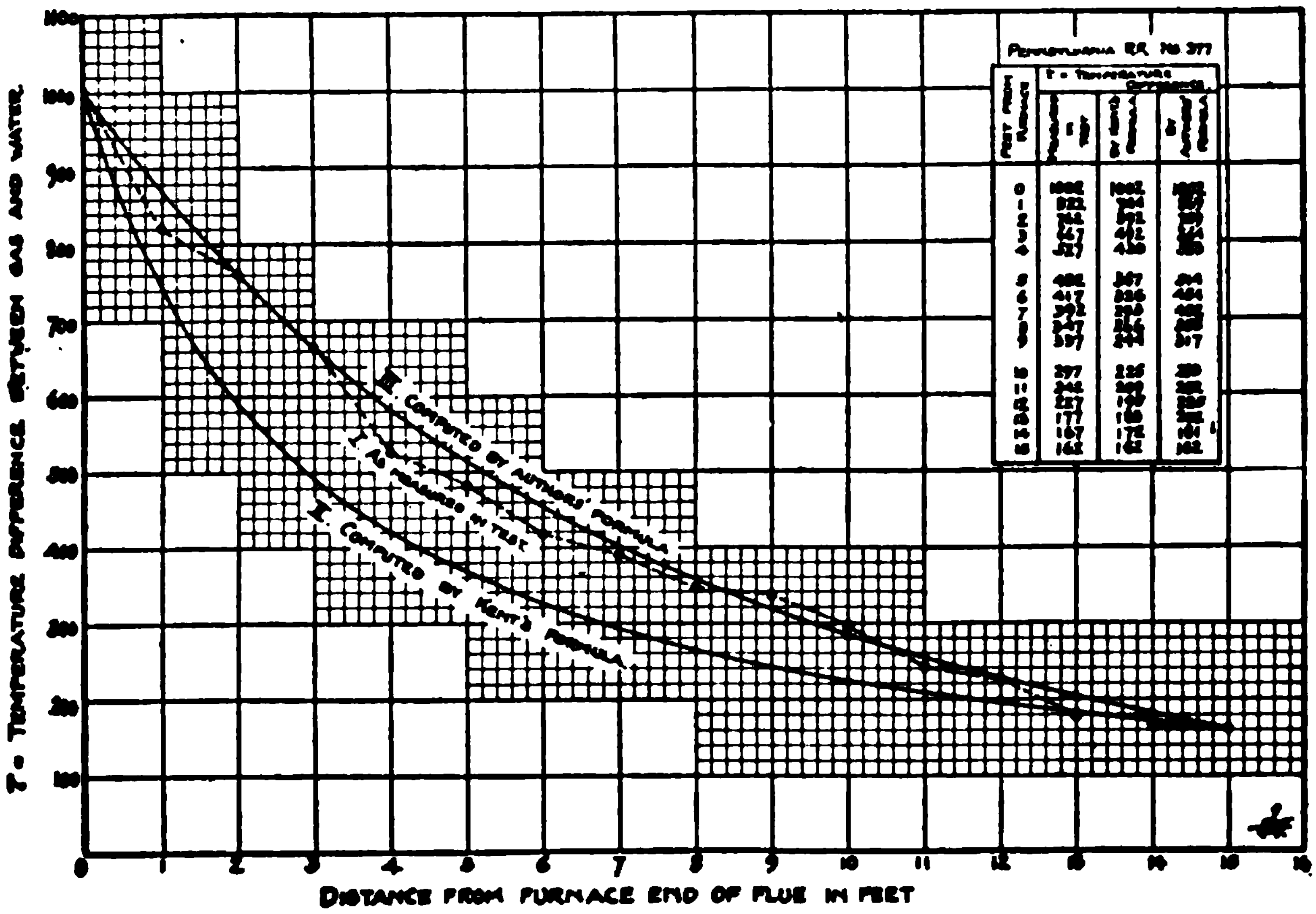

Figure 9.

Equation (55) can be used to check Kent's formula by the Pennsylvania R. R. locomotive tests previously quoted.

In the tables of figures 9 and 10, this has been done by computing the value of K from the initial and final gas temperatures and the tube length,* and then calculating the temperature difference τ_s at

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*From equation (55)

$$K = \frac{\dfrac{1}{\tau_s} - \dfrac{1}{\tau_f}}{S}$$

Substituting τ_o, the final temperature difference, τ_f, the temperature difference at the furnace end, and $S = 15$. (Surface proportional to tube length).

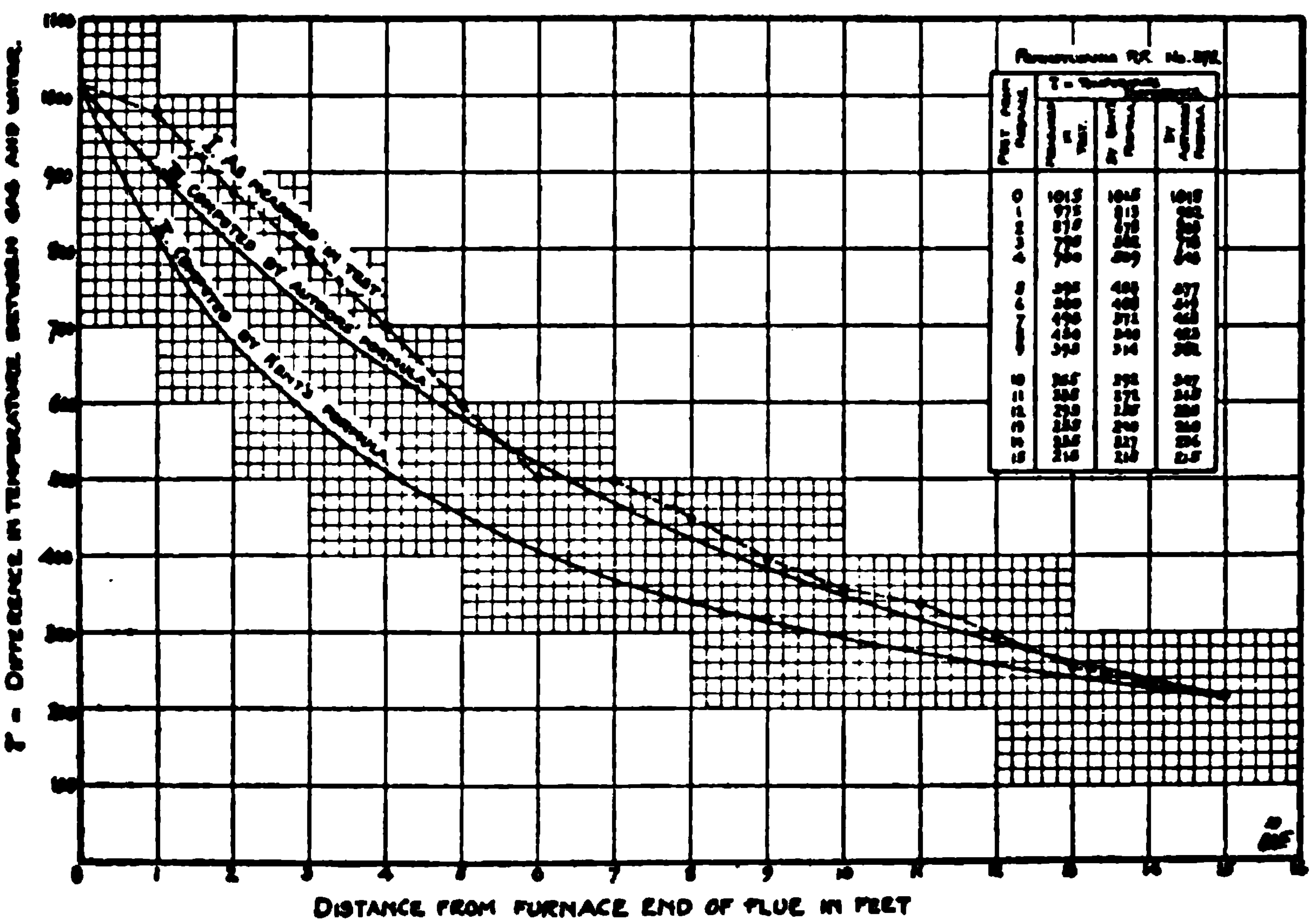


Figure 10.

each foot length of tube by formula (55). For purposes of comparison, the temperatures as computed by the formula advocated by the authors and the temperatures as actually measured are also given.

The same comparison is made in the curves of these figures. In each case curve I shows values of τ as found from the original data, curve II shows τ as computed from Kent's formula and curve III shows τ as computed by the authors' formula. In computing values for curves II and III the variation of the specific heat of the gases could not be taken into account because the composition of the gases was unknown.

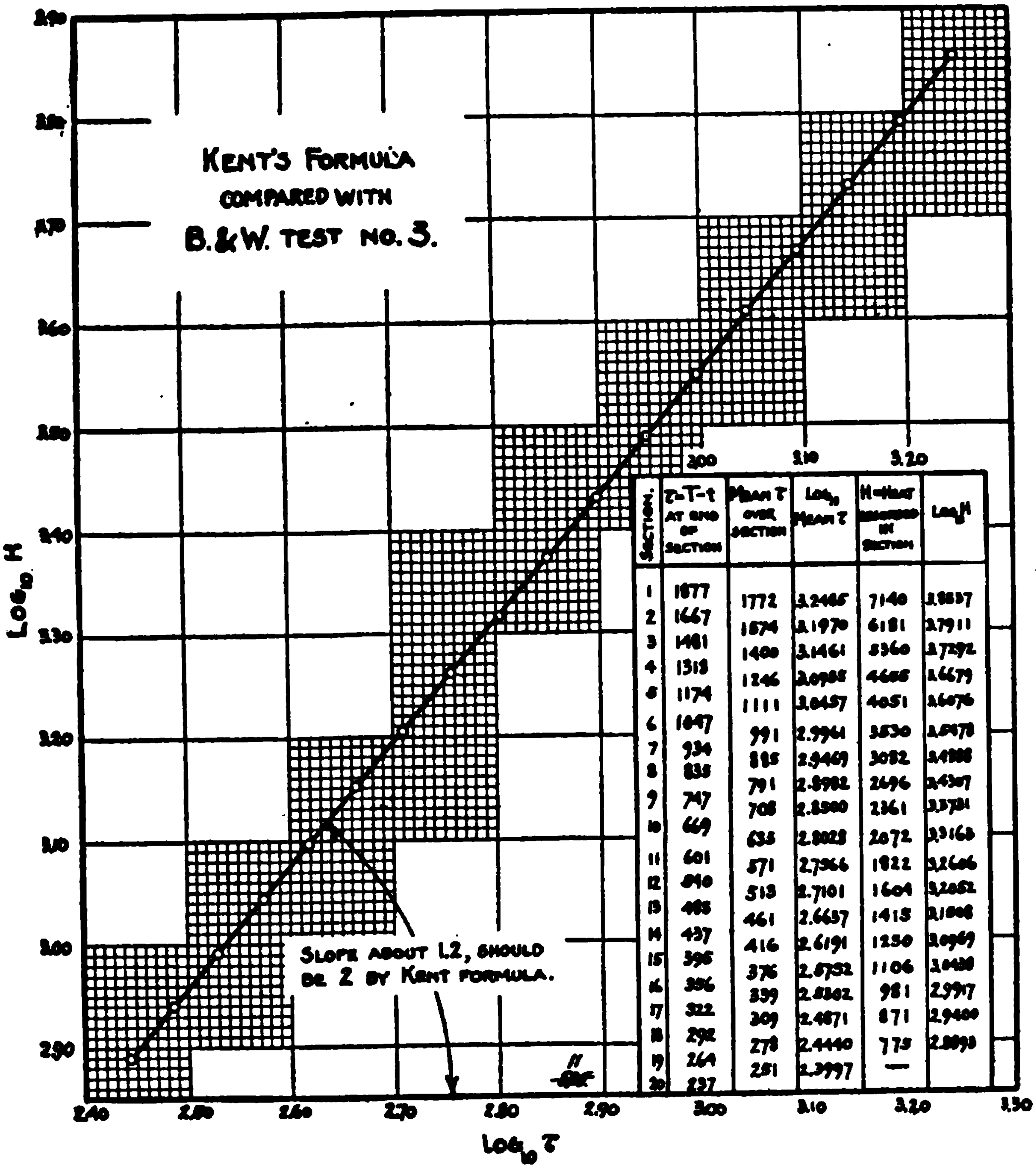
The inadequacy of Kent's formula may be shown in quite another way. Equation (47) may be rewritten as

$$\log H = 2 \log \tau - \log a \tag{56}$$

which is the equation of a straight line whose slope is 2. Figure 11 shows $\log \tau$ plotted against $\log H$ for one of the Babcock and Wilcox experiments (Test No. 3). The figure does indeed show a good straight line, but the slope instead of being 2 is about 1.2. Thus, the formula, instead of being of the form

$$H = \frac{\tau^2}{a} \tag{47}$$

where a is between 160 and 200, as Kent suggests, should be approxi-



SECTION.	$\tau = T - t$ AT END OF SECTION	MEAN τ OVER SECTION	Log_{10} MEAN τ	H = HEAT ABSORBED IN SECTION	$\mathrm{Log}_{10} H$
1	1877	1772	3.2485	7140	3.8537
2	1667	1574	3.1970	6181	3.7911
3	1481	1400	3.1461	5360	3.7292
4	1318	1246	3.0955	4666	3.6679
5	1174	1111	3.0457	4051	3.6076
6	1047	991	2.9961	3530	3.5478
7	934	885	2.9469	3082	3.4888
8	835	791	2.8982	2696	3.4307
9	747	708	2.8500	2361	3.3731
10	669	635	2.8028	2072	3.3163
11	601	571	2.7566	1822	3.2606
12	540	513	2.7101	1604	3.2052
13	485	461	2.6637	1415	3.1508
14	437	416	2.6191	1250	3.0969
15	395	376	2.5752	1106	3.0438
16	356	339	2.5302	981	2.9917
17	322	309	2.4871	871	2.9400
18	292	278	2.4440	775	2.8893
19	264	251	2.3997	—	
20	237				

Figure 11.

mately of the form

$$H = \frac{\tau^{1.2}}{a} \tag{57}$$

where $a =$ (about) 400 if this particular Babcock and Wilcox test is to be satisfied.

GENERAL PLAN OF TESTS

Steam generating equipment can be separated into two parts:

1. The furnace, which liberates the potential energy of the fuel and delivers it in the form of heat in the products of combustion to

2. The boiler proper, in which the heat energy carried by the gases is transmitted to the water to be evaporated.

The present investigation is concerned only with the second division, the boiler proper. The particular question involved in this study is the determination of the law of decrease in temperature of the gases passing over the boiler heating surface.

The simplest method of procedure would seem to be by direct temperature measurements by thermo-couples placed in the gas stream at intervals along the heating surface. There are two objections to this plan:

1. The effect of radiation from the surface of the thermo-couples to the surrounding colder tube walls, thus causing the temperature readings to be too low.

2. Aside from the radiation effect, there is difficulty in locating the thermo-couple so that it would indicate the mean temperature of the gases. This is because the gases are hotter at the center of the tube than near the sides.

On account of the objections connected with direct temperature measurements, the problem was attacked from another standpoint. Instead of searching primarily for the law of decrease in gas temperatures, experiments were made to determine the rate at which heat is absorbed from the gases as they pass over the heating surface. An important phase of the question involved is the effect of gas velocity upon the rate of heat transfer.

In carrying out the experiments, actual boiler conditions were simulated as nearly as possible except that the effect of water circulation was purposely nearly eliminated. The apparatus used consisted of ten small fire tube boiler-sections connected in series so that the same gas passed through all of them. There was no water connection between the sections.

The gases were heated by a gas furnace having air supplied by a blower giving sufficient pressure to force the gases thru the boiler.

Figure 18.

Figure 15.

TABLE NO. 5. DIMENSIONS OF SMALL BOILERS

For series I., one tube, internal diameter, 1.8155 inches.

Section No.	Length of tube in feet	Heating Surface in square feet	Total Heating Surface from furnace end to end of section
1	1.094	.5201	0.5201
2	1.089	.5176	1.0377
3	1.097	.5213	1.5590
4	1.094	.5201	2.0791
5	1.084	.5151	2.5943
6	1.094	.5201	3.1144
7	1.094	.5201	3.6345
8	1.102	.5238	4.1583
9	1.105	.5250	4.6833
10	1.094	.5201	5.2034
For series II, two tubes, internal diameter, 0.816 inches.			
1	1.047	.4474	0.4474
2	1.052	.4494	0.8968
3	1.042	.4452	1.3420
4	1.044	.4460	1.7880
5	1.044	.4460	2.2340
6	1.034	.4418	2.6758
7	1.042	.4452	3.1210
8	1.044	.4460	3.5670
9	1.047	.4474	4.0144
10	1.044	.4460	4.4604
For series III., four tubes, internal diameter, 0.816 inches.			
1	1.047	.8948	0.8948
2	1.052	.8988	1.7936
3	1.042	.8904	2.6840
4	1.044	.8920	3.5760
5	1.044	.8920	4.4680
6	1.034	.8836	5.3516
7	1.042	.8904	6.2420
8	1.044	.8920	7.1340
9	1.047	.8948	8.0288
10	1.044	.8920	8.9208

The steam generated in each section was condensed in a separate surface condenser and accurately weighed. Care was taken to insure that the steam coming from each section was practically dry. The exposed surface of each section was thoroly insulated with hair felt, so that radiation corrections would be small.

The temperature of the gases was measured just as they were leaving the furnace, and just after passing out of the last section. The thermo-couples and thermometer used in these measurements were protected from excessive radiation effects by surrounding them with walls of fire brick.

The gas velocity was varied by changing the speed of the blower supplying air to the furnace, the gas used in the furnace being regulated by a valve. Measurements of gas velocity were made by a pitot tube, but more consistent results were obtained by calculation from the flue gas analysis, the specific heat and the drop in temperature.

The apparatus as assembled, showing boiler, condenser tank, furnace and feedwater connections is shown in figures 12 and 13.

THE FURNACE

The furnace was gas fired, the burner being similar to a large bunsen burner with air supplied under pressure from a 30-inch blower. The gas supplied and blower speed could both be regulated independently in order to obtain any desired temperature in the furnace or gas velocity thru the boiler tubes.

The mixture of gas and air discharged from the burner passed into and burned in a clay muffle surrounded by fire-brick walls 9½ inches thick. Baffles were arranged to thoroly mix the gases before passing to the boiler. The necessary holes were provided for lighting the furnace and for inserting a thermo-couple near the entrance to the boiler tube.

In order to reduce the amount of heat transmitted by radiation and direct conduction from the furnace to the first section of the boiler, three discs of ½-inch asbestos millboard were placed between the furnace and the head of the first section. These discs had holes cut in them the same size as the boiler tube.

THE BOILER

The boiler consisted of ten sections, one of which is shown in longitudinal section in figure 14. Each section had a shell made of a piece of 6-inch pipe, twelve inches long, threaded at both ends. The heads were made by machining the face of a standard 6-inch flange coupling and bolting to it a machined cast-iron disc about ¼ inch thick. The flanges were then screwed on the ends of the shell. The cast-iron discs were bored to receive the tubes which made up the heating surface. One disc on each section was machined with a shoulder 1/16-inch long while the other had a 1/16-inch recess so that

the tubes would be in alignment when the sections were finally bolted together end to end.

The tests may be divided into three series. For series I, the

Figure 14.

heating surface consisted of a single 2-inch tube in each section. For series II, two 1-inch tubes were used, and for series III, four 1-inch tubes. Figure 14 is a longitudinal section for a single section of the boiler of series I. Figure 15 is a cross-section of the boiler of series I and figure 16 of series III. For series II the two upper tubes in figure 16 were blocked off, using only the two lower tubes.

Each section was provided with a water gage glass, thermometer cup, dome, feed pipe and steam outlet. Sections Nos. 1 and 2, nearest the furnace, were also each equipped with a steam separator for insuring dry steam from these sections when the boiler was operated at the higher rates of evaporation.

Table 5, page 31, gives the dimensions and heating surface for each of the ten sections used in the tests.

THE CONDENSERS

Each section of the boiler had its individual condenser so that the condensate from such section could be weighed separately. Each condenser consisted of about 15 feet of ½ inch annealed brass tubing

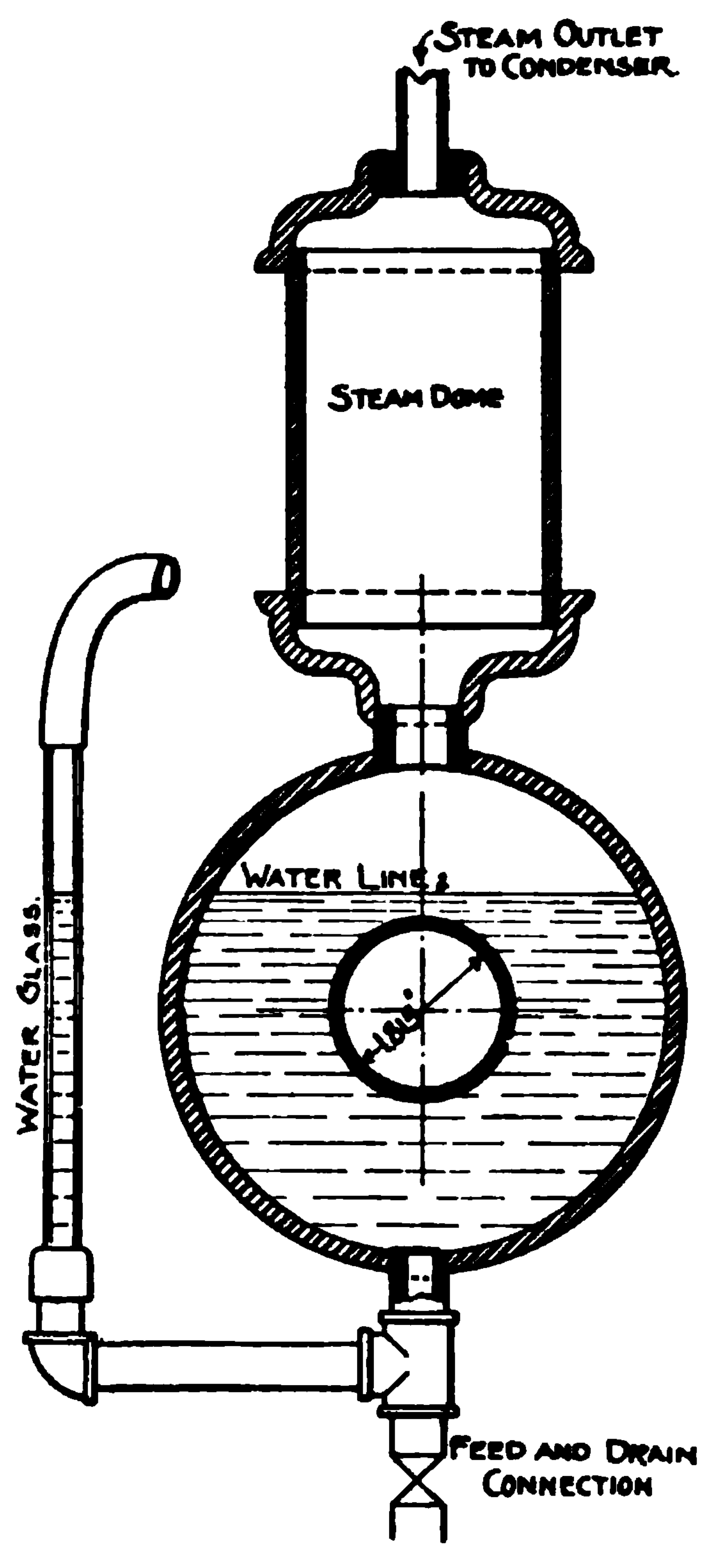


Figure 15.

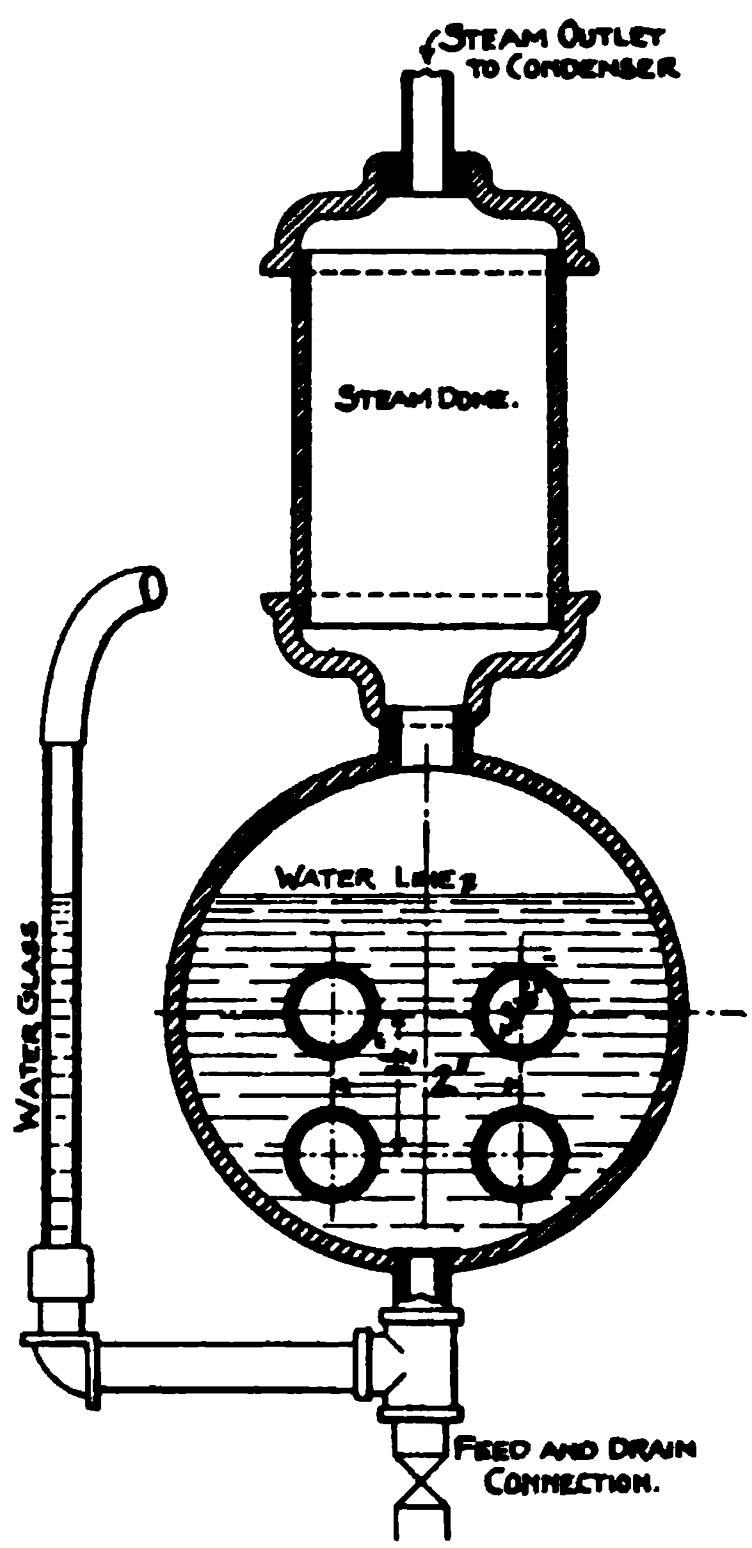


Figure 16.

wound in a 6 inch coil. All these coils were placed in a tank with the lower ends extending through the bottom of the tank, a water-tight joint being made by passing the end of the coil through a rubber stopper and then sealing the stopper in the bottom of the tank. The

cooling tank was about ten feet long, eight inches wide and ten inches deep. This allowed all the coils to be completely submerged and permitted short connections from boiler sections to coils. Cold water was supplied to the tank at the end near the furnace and flowed out at the other end. The cooling tank and rubber tube connections from boiler sections to cooling coils can be seen in figures 12 and 13.

BOILER FEED

The sections were fed separately from a pipe swinging under the entire boiler, each section being connected with this pipe by a ¾-inch rubber tube. The rate of feeding was controlled by a ½-inch gas cock for each section. The main feed pipe was connected to a bucket having an overflow for maintaining a constant head (about three feet above the boiler water line) on the feed line. The control cocks could be set so that the water level in each boiler section could be kept at a constant height as shown by the gage glasses.

MEASUREMENT OF GAS VELOCITY

The velocity head of the gas at the cooler end of the boiler tube was measured with a pitot tube placed at the center of the tube (in series I) and connected to an inclined differential draft gage, reading in inches of water.

For the tests of series II. and III. we could not arrange a pitot tube in each of the boiler tubes. An extension was provided at the exit end of the boiler by which the gases from the different tubes were collected and discharged thru a single pipe. This discharge pipe was 1.391 inches internal diameter for series II. and 2.046 inches for series III. In each case the length was about four feet.

The discharge pipe and connections was well lagged to reduce heat losses. The temperature of the gases was taken in this pipe immediately after leaving the boiler tube and also at the outer end where the pitot tube was inserted.

Many traverses with the pitot tube across the discharge end of the pipe were made in each case in order to establish the relation existing between the velocity at the center of the pipe and the true mean velocity. The mean gas velocity, together with the observed temperature, pressure and gas composition provided data for computing the weight of gases passing per unit of time.

The results obtained from the pitot tube measurements were compared with gas weights computed from the beginning and end gas temperatures together with the total heat transferred from gases to boiler sections. In computing the gas weight on this basis the variation of specific heat with gas composition and gas temperature were taken into account. For series I. the agreement between the two methods

of weight determination was entirely satisfactory. For series II. and III. the pitot tube result was always smaller than that computed from the temperature and heat drop. This was probably due to eddies persisting in the discharge pipe. The results from the second method, being more consistent, were therefore used thruout.

METHOD OF CONDUCTING TESTS

Before starting a test the gas supply and blower speed were adjusted to give the furnace temperature and gas velocity desired. The entire apparatus was then allowed to come to constant conditions with the following points satisfied:

1. Furnace temperature as desired.
2. Gas velocity as desired.
3. Every section steaming at a constant rate.*
4. Water line for each section on a fixed mark on the water gage.

These conditions were kept as nearly constant as possible thruout the test. Most of the tests were two hours in length, a few were 1¾ hours.

Readings were taken thruout each test at uniform intervals of ten minutes for tests where the rate of evaporation was high. For tests where the evaporation rate was low, fifteen minute intervals were allowed between readings.

The water level in each section was kept as near the water line mark on the gage glass as possible. It was often not practicable to adjust the feed water to exactly balance the evaporation especially in the sections near the exit end of the boiler. This resulted in variations in the rate of feeding and in turn caused variations in the evaporation rate. For this reason the tests were made longer than would otherwise have been necessary and the average rate of evaporation over the entire test was used in the final computations. Great care was taken to have the water level thruout the entire boiler the same at the end of the test as at the beginning.

Each section of the condenser was provided with two 600 c.c. beakers for catching the condensed steam. These were kept side by side under the outlet from each condenser section, the condensate being caught in one of them. The beakers were all placed on a board running the entire length of the condenser. This board could be moved endwise, so that when it was time to take readings, the board was shifted to bring the second beaker under the outlet for each condenser section. This method of shifting the beakers proved to be very satisfactory; no water was spilled and all the beakers were

*In many of the tests two to three hours were required to bring the last section to constant steaming conditions, even with hot water applied to the section, before the actual test could be commenced.

changed at the same time. The water caught in the beakers was either weighed in grams or measured in cubic centimeters and later reduced to pounds for each section.

Table 6 is a copy of an original test log together with some of the computations from the test.

TEMPERATURES AND BAROMETRIC PRESSURE

The temperature of the gases was taken immediately before leaving the furnace; this was called the temperature of the gases entering the boiler tube. For this purpose we used a Brown pyrometer, having a platinum-rodium couple and reading up to 3000° F. The pyrometer was calibrated by the manufacturers and was stated to be correct to within 10° F. A rough comparison with Seger cones showed agreement to within 15° F.

The temperature of the gases leaving the boiler tube was taken immediately after leaving the tube, using a 750° F. mercurial thermometer which was compared with a standard of the chemistry department of the University of Missouri. The correction curve was then used to obtain the correct temperature. In some of the tests a centigrade thermometer, similarly calibrated, was used. In order to reduce the inaccuracy due to radiation from the thermometer, a firebrick chamber was built at the exit end of the boiler completely enclosing the thermometer. This also eliminated the stem correction.

Each section of the boiler was fitted with a thermometer, in a thermometer cup filled with oil, for finding the radiation rate of each section. Many determinations of the radiation rate were made and the average, 3.04 B. t. u. per minute per section, was used in all subsequent computations.

The average barometric pressure during each run was obtained from the local U. S. Weather Bureau office and corrected for difference in elevation. This was used in computations for the weight of gases passing through the boiler. Also, since evaporation in the boiler was at atmospheric pressure, the barometer reading was taken as the absolute pressure of evaporation.

DATA TAKEN DURING EACH EXPERIMENT

The following data was taken during each run, at either ten or fifteen minute intervals as previously explained:

t_f = temperature of gases entering the boiler tube.
t_g = temperature of gases leaving the boiler tube.
t_w = temperature of feed water.
(All temperatures are on the ordinary Fahrenheit scale.)
W = water condensed in each section, weighed in grams and reduced to pounds.
h_c = velocity head of the exit gases at the center of the tube, in inches of water.

TEST NO. I 12.
JULY 10, 1914.

TABLE 6.

[illegible] TEMPERATURE, 86° F.
BAROMETER, 29.310 IN.
[illegible] ZERO READING OF PITOT GAGE, [illegible]

OBSERVED DATA.

Time	Temperatures: [illegible] °F	Temperatures: Exit gases °F	Temperatures: Feed water °F	Pitot tube gage	Gas analysis, % by vol.: CO_2	O_2	CO	N_2	Condensed steam from each section, in grams: 1	2	3	4	5	6	7	8	9	10
P.M.																		
2:10	[illegible]	[illegible]	60	[illegible]					0	0	0	0	0	0	0	0	0	0
2:25	[illegible]	276	60	[illegible]	7.4	11.4	0	81.2	630	328	271	229	180	185	161	136	102	85
2:40	[illegible]	270	60	[illegible]					691	[illegible]	297	272	219	178	156	120	96	87
2:55	[illegible]	270	60	[illegible]					646	330	257	201	182	148	121	109	64	51
3:10	[illegible]	274	60	[illegible]	7.2	11.0	0	81.0	684	340	284	273	219	192	162	135	106	91
3:25	[illegible]	277	60	[illegible]					606	352	304	248	215	169	135	110	100	85
3:40	[illegible]	270	60	[illegible]	[illegible]	[illegible]	0	81.0	689	344	[illegible]	228	192	178	165	127	101	87
3:55	[illegible]	[illegible]	60	[illegible]					651	342	175	260	203	162	130	132	92	101
4:10	[illegible]	[illegible]	60	[illegible]					672	319	292	267	218	197	167	140	109	94
Mean	[illegible]	[illegible]	60	[illegible]	7.0	[illegible]	0	[illegible]										

COMPUTED RESULTS.

Heat to produce one pound of dry steam = [illegible] = 1113.9 B.T.U.

Heat to produce one gram of dry steam = 1113.9 × 0.0022046 B.T.U.

Heat absorbed per minute in any section = Total condensate from that section × $\frac{1113.9 \times 0.0022046}{120}$ B.T.U.

	For section: 1	2	3	4	5	6	7	8	9	10
Grams evaporated in 120 minutes = G	[illegible]	2725	2748	[illegible]	[illegible]	1409	1187	1009	775	[illegible]
B.T.U. per minute = $G \times \frac{1113.9 \times .0022046}{120}$ = H'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Corrected B.T.U. per minute = H' + 2.04[2]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27.35	[illegible]	[illegible]	[illegible]
Σ_1(B.T.U. per min)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% of total evaporation in each section = P	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Σ_1(P)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Equiv. evap. from and at 212° F. = [illegible]	[illegible]	3.64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Equiv. evap. per sq. ft. heating surface, per hr.	[illegible]	7.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

GAS CALCULATIONS.

Pounds of gases per minute, based on heat content = [illegible] = [illegible]

Gas weight checked by Pitot tube.
Velocity head as read = [illegible]
Factor to change head at center to mean velocity head = 0.86
Specific gravity of oil in gage = [illegible]
Actual mean velocity head = [illegible] = h

Weight of 1 cu. ft. gas at [illegible] °F and 29.310 barometer = [illegible] pounds

Gas velocity at exit = $\sqrt{2gh \times [illegible]}$ = [illegible] = [illegible] ft. per sec.

Cu. ft. gas per min. = [illegible] = 33.33 Pounds gas per min = 33.33 × [illegible] = [illegible]

NOTES: (1) Pitot tube connected to differential gage to read velocity head at center of tube. The gage was connected so that readings [illegible] as head increased.
(2) Radiation correction found by separate experiment = 2.04 B.T.U. per section per minute.
(3) The constant [illegible] is derived as follows:
At any temperature, T, and barometer, B, the density, [illegible] = [illegible]
= [illegible]
Cf. [illegible], p. [illegible]

TEST NO. I 12 COMPUTATIONS CONTINUED. TABLE 6. CON'D.

CURVES OF $\log_{10}\left[\log_{10}\frac{H}{H_w}\right]$ VS. HEATING SURFACE PASSED OVER.

B.T.U. PER POUND OF GASES, ABOVE 32°F., LEAVING SECTION 10,	126.40
" " " " " , TO RAISE FROM 0° ABS. TO 32°F., (CO_2 = 7.1%),	115.88
" " " " " , ABOVE 0° ABS., LEAVING SECTION 10,	242.28

H_{10} = 242.28 × 1.4746 (= WGT.) = 357.27 B.T.U. PER MINUTE, LEAVING SECTION 10.
414.36 " " " , ABSORBED IN ENTIRE BOILER.
H_0 = 771.63 " " " LEAVING FURNACE.

B.T.U. PER POUND OF GASES, ABOVE 32°F, AT WATER TEMPERATURE, 212°F,	44.28
" " " " " , TO RAISE FROM 0° ABS. TO 32°F,	115.88
" " " " " , ABOVE 0° ABS., AT 212°F,	160.13

H_w = 160.13 × 1.4746 = 236.13 B.T.U. PER MINUTE FOR GASES AT WATER TEMPERATURE.

DIRECT COMPUTATIONS, USING HEAT ABSORBED IN EACH SECTION AS FOUND BY EXPERIMENT.

SECTION No.	B.T.U. ABSORBED PER MINUTE.	H = B.T.U. ABOVE 0° ABS. LEAVING SECTION.	$\frac{H}{H_w}$	R = $\log_{10}\frac{H}{H_w}$	Θ = $\log_{10} R$
FURN.	——	771.63	3.2677	0.51424	9.71117
1	103.61	663.02	2.8078	0.44837	9.65164
2	58.80	604.22	2.5588	0.40804	9.61070
3	48.94	555.28	2.3515	0.37135	9.56976
4	43.52	511.76	2.1672	0.33590	9.52621
5	35.74	476.02	2.0201	0.30537	9.48485
6	31.87	444.15	1.8809	0.27437	9.43834
7	27.33	416.82	1.7652	0.24679	9.39235
8	23.69	393.13	1.6648	0.22136	9.34510
9	18.90	374.23	1.5848	0.19997	9.30096
10	16.96	357.27	1.5130	0.17984	9.25489

REVERSED COMPUTATIONS, ASSUMING CURVE $\log_{10}\left[\log_{10}\frac{H}{H_w}\right]$ VS. X TO BE A STRAIGHT LINE.

$\Theta_1 = \log_{10} R_1$	$R_1 = \log_{10}\frac{H'}{H_w}$	$\frac{H'}{H_w}$	H'	(B.T.U.)' ABSORBED PER MINUTE.	SECTION No.
9.71117	0.51424	3.2677	771.63	——	FURN.
9.66554	0.46296	2.9038	685.67	85.96	1
9.61991	0.41678	2.6108	616.49	69.18	2
9.57429	0.37522	2.3726	560.24	56.25	3
9.52866	0.33780	2.1767	513.98	46.26	4
9.48303	0.30411	2.0142	475.61	38.37	5
9.43740	0.27378	1.8784	443.55	32.06	6
9.39177	0.24647	1.7639	416.51	27.04	7
9.34615	0.22190	1.6669	393.61	22.90	8
9.30052	0.19977	1.5841	374.05	19.56	9
9.25489	0.17984	1.5130	357.27	16.78	10

MEAN SLOPE OF CURVE, PER SECTION, $M_1 = 0.045628$.

" " " PER SQ. FT. OF HEATING SURFACE, $= M_2 = \frac{9.71117 - 9.25489}{5.20338} = 0.087688$

" " " , PER FOOT LENGTH OF TUBE $= \frac{0.45628}{10.948} = 0.04168$.

HEAT CONTENT CONSTANTS.

CONSTITUENT GASES	w = % BY WGT	$\frac{wA_1}{100}$	$\frac{wB_1}{100}$	$\frac{wC_1}{100}$
CO_2	10.03	0.023159	0.000007331	−0.000000001414
CO	——	——	——	——
O_2	12.16	0.027421	0.000002099	
N_2	72.90	0.178824	0.000012349	
H_2O	4.91	0.022351	−0.000001502	+0.000000002018
SUM FOR THE MIXTURE		A_2 = 0.251755	B_2 = 0.000020327	C_2 = 0.000000000604

TEST NO. I 12. COMPUTATIONS CONTINUED. TABLE 6. CONT'D.

GAS HEAT CONTENT ABOVE 212° F.

$A_2 = .251738$
$B_2 = .000020237$
$C_2 = .000000000604$

T-212	$A_2[T-212]$	$B_2[T-212]^2$	$C_2[T-212]^3$	$H-H_{212}$	Diffs.
1300	327.26	34.20	1.34	362.80	30.53
1200	302.08	29.14	1.05	332.27	30.07
1100	276.91	24.49	.81	302.20	29.61
1000	251.74	20.24	.61	272.59	29.20
900	226.56	16.39	.44	243.39	28.74
800	201.39	12.95	.31	214.65	28.39
700	176.21	9.92	.21	186.26	27.80
600	151.04	7.29	.13	158.46	27.45
500	125.87	5.06	.08	131.01	27.04
400	100.69	3.24	.04	105.97	26.61
300	75.52	1.82	.02	77.36	

COMPUTATIONS FOR HEAT TRANSMISSION COEFFICIENT AND TUBE EFFICIENCY.

	Furn.	1	2	3	4	5	6	7	8	9	10
B.T.U. above 212° leaving each section	535.50	449.80	380.36	324.11	277.35	239.48	207.42	180.38	157.48	137.92	121.14
Do., per pound of gas, (wt = 1.4746)	363.18	304.83	257.94	219.80	188.42	162.40	140.66	122.32	106.80	93.53	82.15
B.T.U. per lb. at nearest even 100°,	362.80	302.20	243.39	214.65	186.26	158.46	131.01	131.01	105.97	103.97	77.36
Difference,	.38	2.63	14.55	5.15	2.16	3.94	9.65	-8.69	2.83	-10.44	4.79
Difference for 100°,	30.53	30.07	29.20	28.74	28.39	27.80	27.45	27.45	27.04	27.04	26.61
$\tau = T - 212°$,	1801	1109	980	818	708	615	535	467	408	369	316
$\tau_n \div \tau_m = q$,		1.173	1.167	1.161	1.155	1.153	1.148	1.143	1.142	1.136	1.135
$\log_{10} q$,		.0695	.0672	.0650	.0627	.0619	.0598	.0581	.0575	.0553	.0551
$\log_e q$,		.1597	.1548	.1496	.1444	.1425	.1378	.1338	.1324	.1272	.1268
$\tau_n - \tau_m$,		192	159	132	110	95	78	68	59	49	43
Mean τ over section = approx. $\frac{\tau_n - \tau_m}{\log_e q}$		1208	1027	882	762	660	573	501	438	386	339
S = sq. ft. heat. surf. in each sect.		.5201	.5176	.5213	.5210	.5151	.5201	.5201	.5328	.5250	.5201
Mean $\tau \times S$,		625.7	531.6	459.8	397.0	340.0	298.0	260.6	233.4	202.1	176.3
Heat absorbed in section, = h,		85.96	69.18	56.25	46.26	38.37	32.06	27.04	22.90	19.56	16.76
$C = \frac{60h}{\text{Mean } \tau \times S}$,		8.243	7.808	7.340	6.991	6.772	6.455	6.226	5.888	5.806	5.704
$\frac{H - H_x}{H_0 - H_w}$,	1.0000	.8394	.7103	.6062	.5189	.4472	.3873	.3368	.2941	.2576	.2262
Efficiency up to end of each section $= 1 - \frac{H - H_x}{H_0 - H_w}$, %	0.0	17.06	28.93	39.48	48.11	55.28	61.27	66.32	70.59	74.24	77.38

The exit gases were analyzed three or four times during each test, using an ordinary Orsat apparatus. The results were used in determining the specific weight of gases passing and also their heat content at different temperatures. The computations involved will be explained later.

At the close of several of the tests the fuel and air supply to the furnace was cut off and the connection between the boiler and furnace removed and replaced by a partition of asbestos millboard to reduce the transmission of heat by radiation and conduction from the furnace to the first section of the boiler. A series of readings was then taken to determine the radiation rate. The temperature of the water in each

section was read every five minutes for a period of two hours. The water was then drawn off and weighed. Knowing the weight of the water which had been in each section and the water equivalent of the metal in the section, the heat radiated for each five minutes was calculated. The amounts so obtained plotted against time, gave a nearly straight line, the radiation rate decreasing as time increased and the boiler cooled off. This line produced till it cut the zero time axis gave an intersection which indicated the average rate of radiation during the run. Since the evaporation was at atmospheric pressure in all tests, the temperature of the water and metal was practically the same for all tests; the room temperature did not vary greatly. Hence the radiation rate should be the same for all tests. The data taken as described above confirmed this statement. The average of several such determinations was 3.04 B. t. u. per minute per section. In making the radiation tests the result from the first section was disregarded because it probably received heat thru the asbestos partition from the hot furnace walls.

METHODS OF CALCULATION

Heat Absorbed by Each Section. The heat absorbed by the water in any section in one minute equals the weight of the condensed steam per minute for that section multiplied by the heat required to produce one pound of dry steam at atmospheric pressure starting with feed water at the observed temperature. The radiation correction added to the quantity just found gives the total heat absorbed by the section. Table 6 shows the data as taken for one test together with the computed value of the heat absorbed per minute in each section. All the tests were worked out in the same manner, the results being shown in Tables 7 and 8.

Moisture in Gases. During each run the exit gas was frequently analyzed with an Orsat apparatus, giving the percent by volume in the dry gas of the following constituents: carbon dioxide, oxygen, and carbon monoxide. The remainder of the 100 per cent. was taken as nitrogen. It is necessary to know the amount of water vapor in the gases before any accurate determination of the heat capacity can be made. The following plan was used to estimate the moisture content:

The flue gas burned in the furnace was analyzed by a representative of the chemistry department from time to time during the series of tests. From this analysis was calculated the weight of water vapor and the weight of carbon dioxide which would result from perfect combustion. From these computations, let

$$w = \frac{\text{per cent. by weight of water vapor}}{\text{per cent. by weight of carbon dioxide}}.$$

This ratio remains constant irrespective of the amount of air supplied for combustion.

It was assumed that in the actual tests all the hydrogen in the original fuel would burn to water vapor and all the carbon to carbon dioxide or carbon monoxide. The weight of the carbon dioxide which should be produced by the complete combustion of any carbon monoxide formed added to the weight of carbon dioxide actually formed is the weight of carbon dioxide which would be formed if combustion were complete. This weight of carbon dioxide multiplied by the ratio w found above should give the weight of water vapor actually present, neglecting that in the air supply to the furnace.

The plan as outlined above was checked by passing a known volume of the flue gases through sulphuric acid and calcium chloride, noting the increase in weight of the driers. The check was satisfactory.

Heat Capacity of Gases. In computing the heat content of the products of combustion the following values for the instantaneous specific heat of the several constituent gases were used. The temperatures are in degrees Fahrenheit.

$$\text{For}\quad\left.\begin{array}{ll} CO_2, & C_p = .2032 + .0001614\,(t-32) - .0000000423\,(t-32)^2 \\ H_2O \text{ vapor}, & C_p = .4698 - .0001056\,(t-32) + .0000001233\,(t-32)^2 \\ O_2, & C_p = .2194 + .00003386\,(t-32) \\ N_2 \text{ and } CO, & C_p = .2392 + .00003388\,(t-32) \end{array}\right\} \quad (58)$$

These are combinations of values given by several authorities;* their accuracy is somewhat doubtful, since there is considerable variation in the results of different experimenters. Using these values for the instantaneous specific heat, the heat content in B. t. u. per pound above 32° F for the various gases at any temperature (t° F) is

$$\text{For}\quad\left.\begin{array}{ll} CO_2, & H = .2032\,(t-32) + .0000807\,(t-32)^2 - .0000000141\,(t-32)^3 \\ H_2O \text{ vapor}, & H = .4698\,(t-32) - .0000528\,(t-32)^2 + .0000000411\,(t-32)^3 \\ O_2, & H = .2194\,(t-32) + .00001693\,(t-32)^2 \\ N_2 \text{ and } CO, & H = .2398\,(t-32) + .00001694\,(t-32)^2 \end{array}\right\} \quad (59)$$

The heat content equations are developed as follows:

Let the instantaneous value of the specific heat be

$$C_p = a + b\,(t-32) + c\,(t-32)^2 \qquad (60)$$

For a small change in temperature, dt, the corresponding change in heat content is

$$dH = C_p dt \qquad (61)$$

If this expression is integrated between 32° and any desired tempera-

*References for specific heat data: Lucke, "Engineering Thermodynamics"; Goodenough, "Principles of Thermodynamics"; Somermeier, "Coal".

ture, t, the result is the heat capacity between 32° and t°. Thus

$$H = \int_{32}^{t} dH = \int_{0}^{t-32} [a + b\,(t - 32) + c\,(t - 32)^2]\,dt$$

$$= \Big[a\,(t - 32) + \frac{b}{2}\,(t - 32)^2 + \frac{c}{3}\,(t - 32)^3 \Big]_{0}^{t-32}. \qquad (62)$$

Substituting,

$$A = a$$

$$B = \frac{b}{2}$$

$$C = \frac{c}{3}$$

in equation (5) gives

$$H = A\,(t - 32) + B\,(t - 32)^2 + c\,(t - 32)^3 \qquad (63)$$

It is sometimes desirable to form equations for the heat content using some other base than 32°, for example, 212°. The form of the equation will be the same as (63) but the constants will be changed. Thus

$$H_1 = A_1\,(t - k) + B_1\,(t - k)^2 + C_1\,(t - k)^3 \qquad (64)$$

Where A_1, B_1 and C_1 are the new values of the constants and k the new base temperature. In general, if $z = k - 32$

$$\left.\begin{aligned} A_1 &= A + 2Bz + 3Cz^2 \\ B_1 &= B + 3Cz \\ C_1 &= C. \end{aligned}\right\} \quad (65)$$

In some of the work to follow the values of A_1, B_1 and C_1 are required, where $k = 212$. These have been computed by eq. (65) from the values of A, B and C in eq. (59), and are as follows:

Gas	A_1	B_1	C_1
N_2 and CO	.2453	.00001694	0
O_2	.2255	.00001693	0
CO_2	.2309	.00007309	— .0000000141
H_2O	.4548	—.0000306	+ .0000000411

If the gas is a mixture made up of,

CO_2, m per cent.
O_2, n per cent.
N_2, q per cent.
H_2O, p per cent.

the value of the constants for a single equation for determining the heat content (above 212°) for the mixture are

$$\left.\begin{aligned} A_2 &= (.2309m + .2255n + .2453q + .4845p) \div 100 \\ B_2 &= (.00007309m + .00001693n + .00001694q - .0000306p) \div 100 \\ C_2 &= (-.0000000141m + .0000000411q) \div 100 \end{aligned}\right\} \quad (66)$$

In certain other computations to be used later, it is necessary to know the heat capacity of the gases above absolute zero. For this purpose we have applied the equations just developed to temperatures below 32° F. and added the result to the heat content above 32° F.

The following considerations led us to express the heat content from absolute zero to 32° F as a function of the per cent. by weight of carbon dioxide:

1. The weight of water vapor is proportional to the weight of carbon dioxide.

2. The weight of nitrogen is nearly constant and is the predominating factor.

3. The relation between the volumes of carbon dioxide and free oxygen is simple.

These facts permit the three variables, carbon dioxide, water vapor and oxygen, to be expressed as a function of one of them and carbon dioxide was chosen.

It was found that the tests could be all distributed in two groups, limited by certain dates which were identified with changes in the method of manufacture of the fuel gas. These changes affected the ratio between the weight of carbon and hydrogen in the gas and therefore also the ratio between the weights of carbon dioxide and water vapor in the products of combustion.

The characteristics of the two groups and the resulting heat contents are given in the following tables:

TABLE 9. GROUP CHARACTERISTICS

	GROUP 1	GROUP 2
Limiting dates	March 13, 1914 —March 27, 1914	April 10, 1914 to end of tests.
Ratio of weight of water vapor to carbon dioxide.	0.673	0.490
$CO_2 \times O$ (per cents by volume in dry gas)	75	82

TABLE 10. HEAT CONTENT FROM ABSOLUTE ZERO TO 32° F.

% CO_2 BY VOLUME IN THE DRY GAS	HEAT TO RAISE FROM ABSOLUTE ZERO TO 32° F. B. T. U.	
	GROUP 1	GROUP 2
5%	116.37	.....
6%	117.42	115.11
7%	118.33	115.83
8%	119.81	116.34
9%	.....	116.82
10%	.....	117.31

On pages 46 to 53 are tabulated the entire mass of collected and computed data for all of the tests. In every case the computations were made in the same way as is indicated for test number I 12 given on pages 38 to 40.

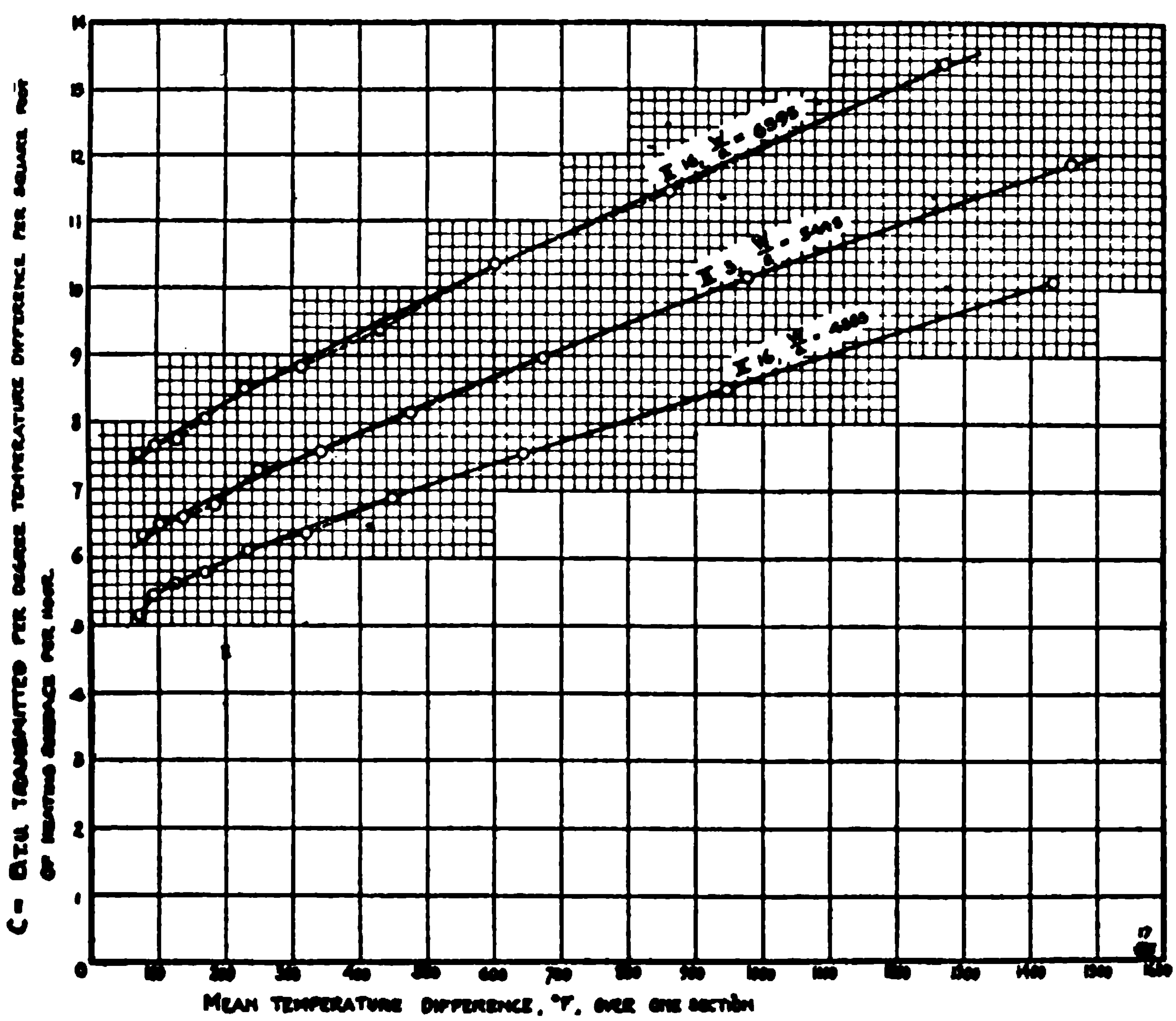


Figure 17.

THE COEFFICIENT OF HEAT TRANSMISSION

The coefficient of heat transmission thru any material is commonly defined as the number of heat units transmitted thru a unit surface of unit thickness per unit of time and per degree temperature difference between the hot and cold surfaces of the material. In this discussion, however, several different kinds and states of material are involved and this definition is hardly applicable. Instead, we shall consider the coefficient of heat transmission to be the number of heat units (*B. t. u*) transmitted per hour per square foot of heating surface (measured on the inside of the tube) per degree temperature difference between the boiler water and the hot gases.*

Strictly interpreted the application of even this definition is questionable. Our experiments, as well as those of the Babcock and Wilcox Co., indicate that the rate at which the heat is transferred from gases to water is not directly proportional to the temperature difference, but that the rate itself depends on the temperature difference. The idea of a "coefficient of heat transmission" is so universally prevalent, however, that some justification exists for endeavoring to use it in expressing the results of these experiments.

Attempts to get a formula for the coefficient by mathematical reduction from the equations already developed resulted in such complicated expressions that they were discarded as useless. The formulæ given below are obtained by plotting the experimental results and are entirely empirical.

On page 38 are shown sample computations for finding the gas temperature at any point along the tube, the heat lost by the gases in passing thru each section of the boiler, the mean temperature over each section and the coefficient of heat transmission, as defined above, all on the assumption that equation (19) is a true statement of the conditions obtaining. A similar set of computations was made for each test run, the results being shown in the general tabulation on pages 49 and 53. From these figures a curve was plotted for each test similar to the ones shown in figure 17. Having these curves for all the tests, another series of curves were plotted as shown in figure 18 using points picked from the curves of figure 17 for each even hundred degrees temperature difference. It was then assumed that straight lines could be made to pass thru each series of points so that an equation of the form

$$C = A + B\frac{W}{a} \tag{67}$$

*By temperature of the hot gases is meant the true mean temperature of all the gas passing a given point at a given instant.

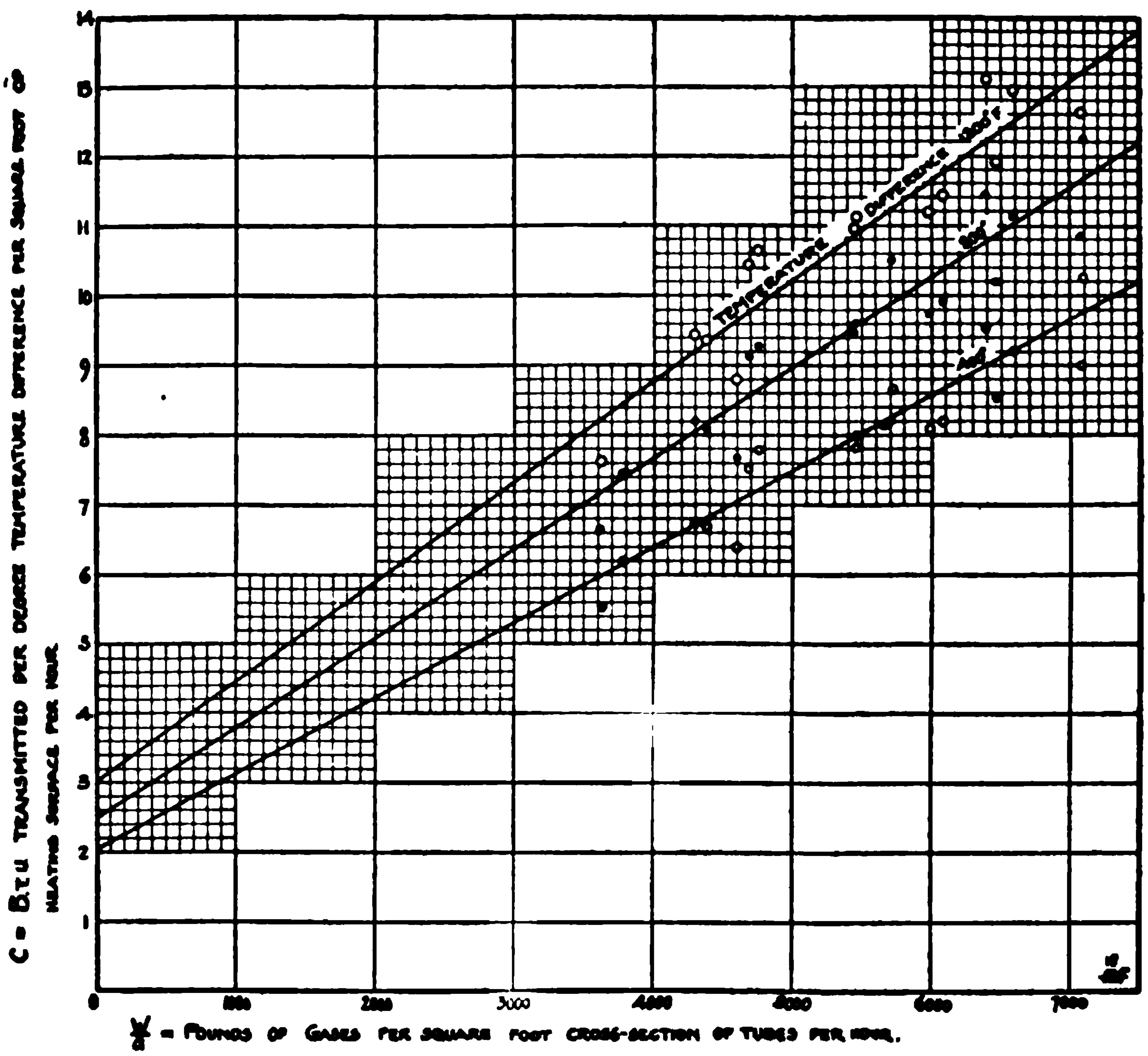


Figure 18.

could be used for the coefficient of heat transmission.* The lines which are shown in the figure were obtained by using all the points available and solving for A and B by least squares. The points as plotted indicate that the line should curve downward slightly at the left end.

Figure 19 shows the completed family of straight lines for series I. and figure 20 for series II. and III. It is apparent from these figures that neither A nor B are constant. The values of A and B can be fairly well expressed by the following equations:

For Series I.,

$$A = 1.000 + .00087r \qquad (68)$$

$$B = .00000141r^{\text{[illegible]}} + .0008077 \qquad (69)$$

*This is identical with the Bureau of Mines formula, eq. (2).

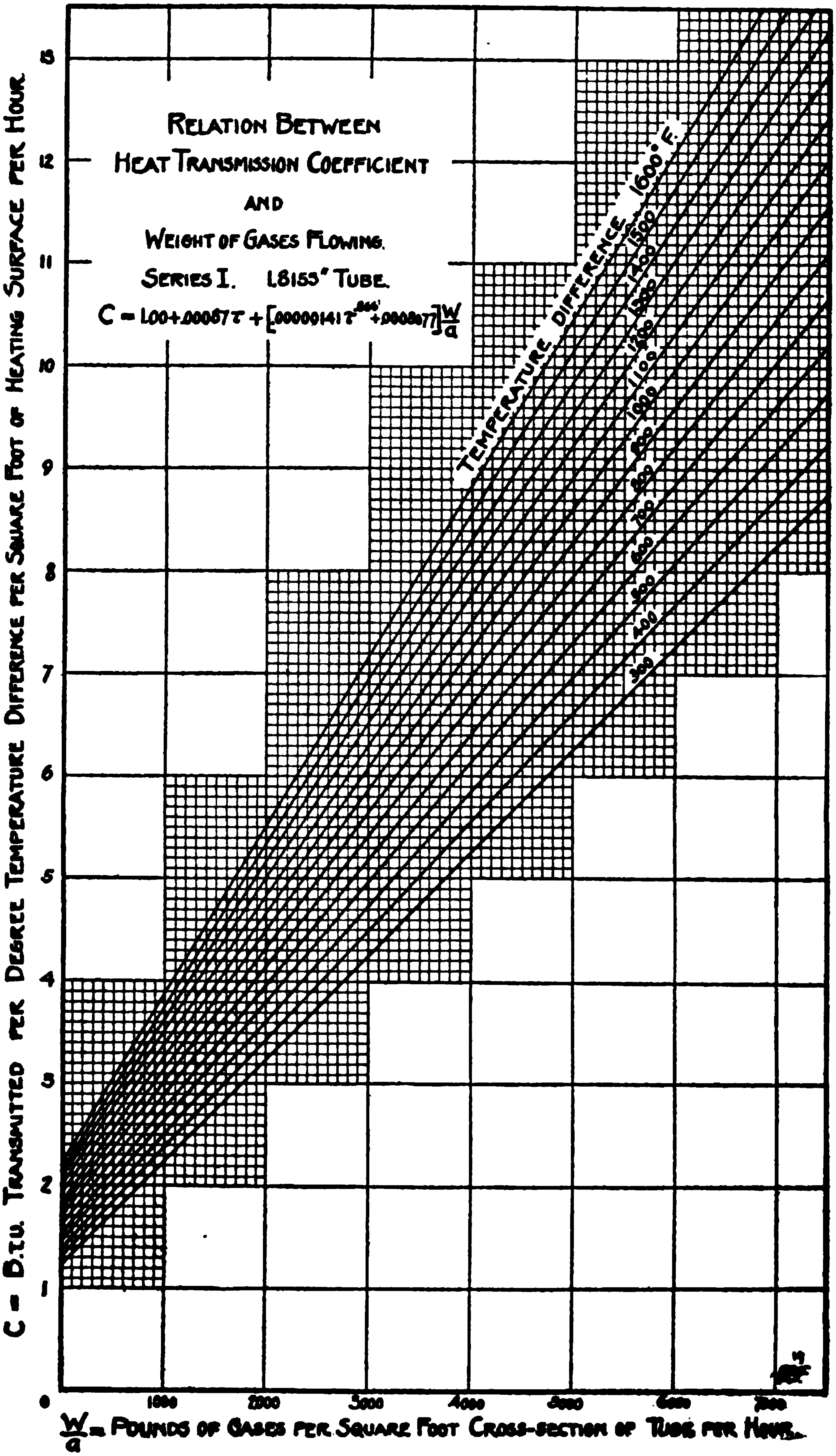

Relation Between
Heat Transmission Coefficient
and
Weight of Gases Flowing.
Series I. 1.8155" Tube.
Temperature Difference 1600° F.
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
C = B.t.u. Transmitted per Degree Temperature Difference per Square Foot of Heating Surface per Hour.
W/a = Pounds of Gases per Square Foot Cross-section of Tube per Hour.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
1000
2000
3000
4000
5000
6000
7000

Figure 19.

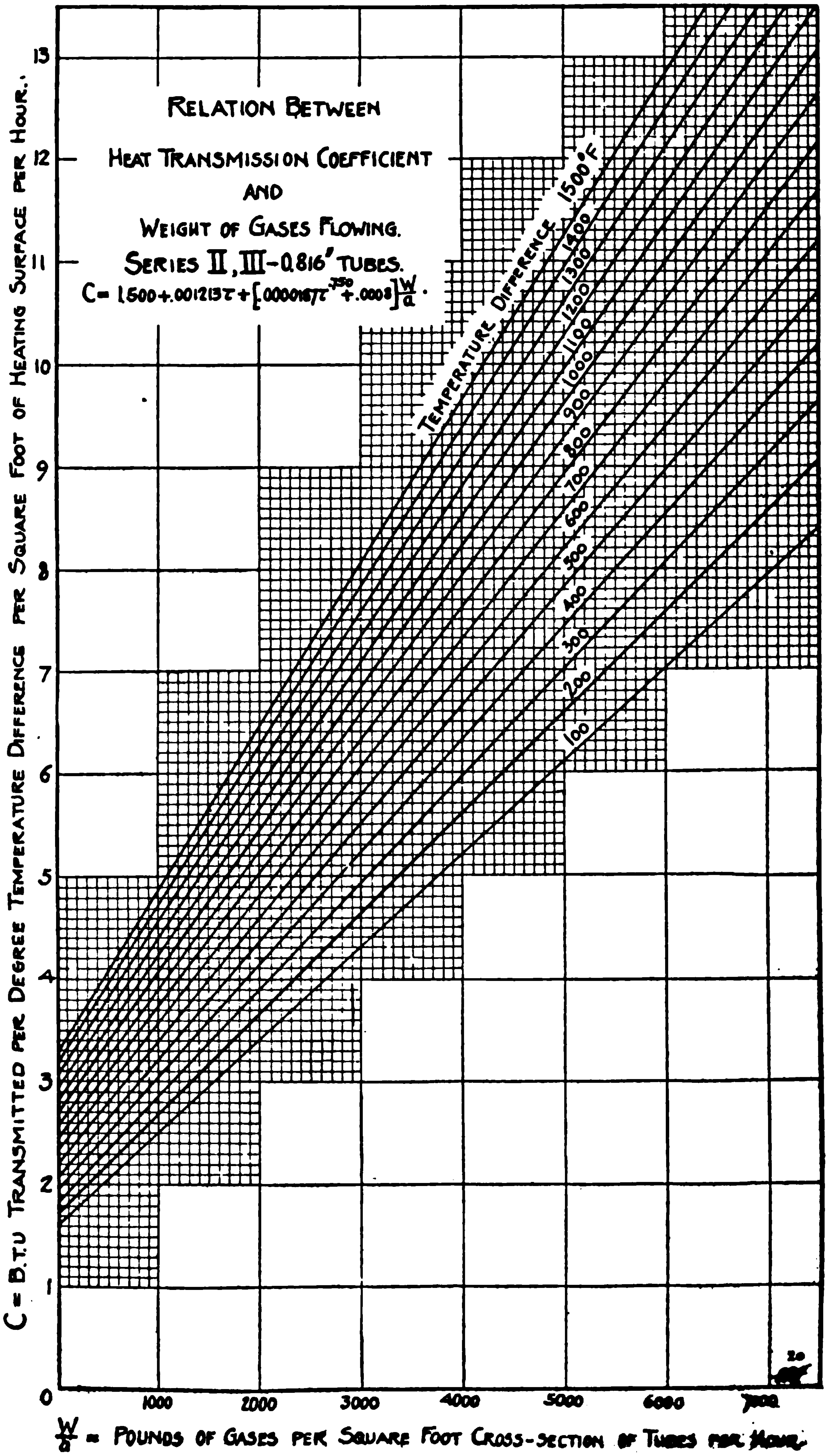

RELATION BETWEEN
HEAT TRANSMISSION COEFFICIENT
AND
WEIGHT OF GASES FLOWING.
SERIES II, III – 0.816" TUBES.
$C = 1.500 + .001213\tau + [.0000167\tau^{.750} + .0008]\frac{W}{a}$.
TEMPERATURE DIFFERENCE 1500°F
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
1000
2000
3000
4000
5000
6000
7000
C = B.T.U TRANSMITTED PER DEGREE TEMPERATURE DIFFERENCE PER SQUARE FOOT OF HEATING SURFACE PER HOUR.
$\frac{W}{a}$ = POUNDS OF GASES PER SQUARE FOOT CROSS-SECTION OF TUBES PER HOUR.

Figure 20.

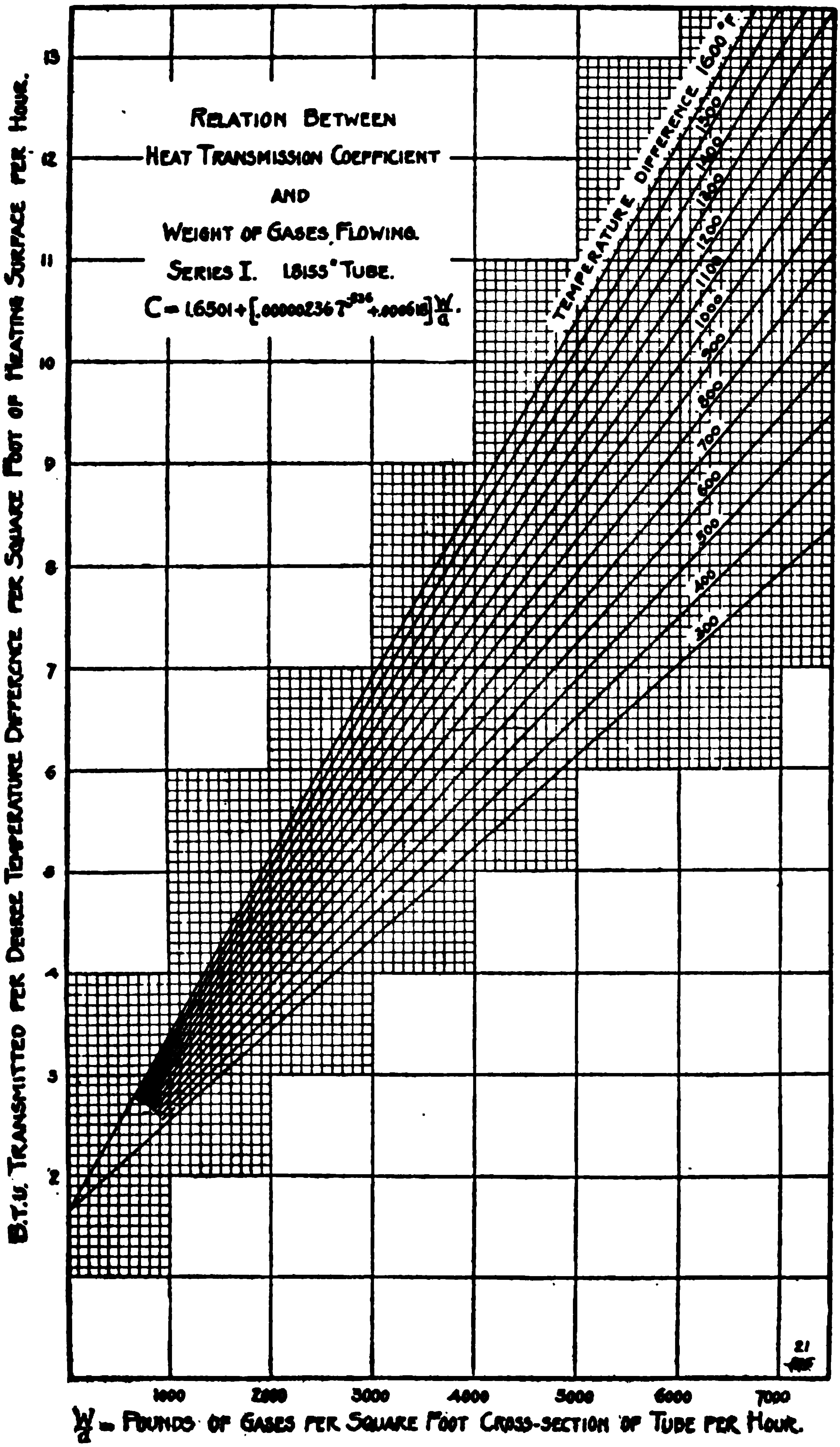

RELATION BETWEEN
HEAT TRANSMISSION COEFFICIENT
AND
WEIGHT OF GASES FLOWING.
SERIES I. 1.8155" TUBE.
TEMPERATURE DIFFERENCE 1600°F.
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
B.T.U. TRANSMITTED PER DEGREE TEMPERATURE DIFFERENCE PER SQUARE FOOT OF HEATING SURFACE PER HOUR.
2
3
4
5
6
7
8
9
10
11
12
13
1000
2000
3000
4000
5000
6000
7000
W/a = POUNDS OF GASES PER SQUARE FOOT CROSS-SECTION OF TUBE PER HOUR.

Figure 21.

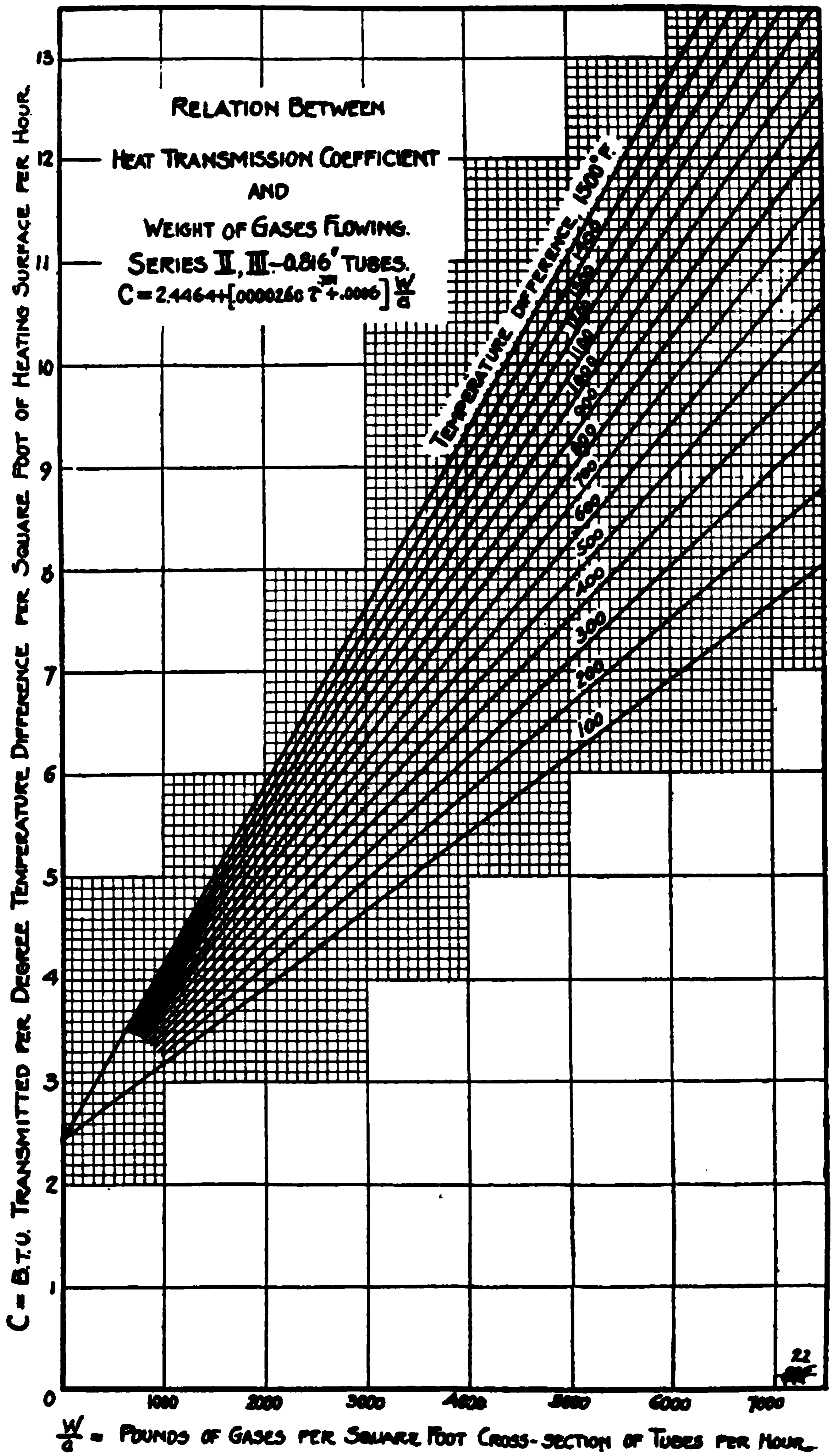

RELATION BETWEEN
HEAT TRANSMISSION COEFFICIENT
AND
WEIGHT OF GASES FLOWING.
SERIES II, III—0.816' TUBES.
C = 2.4464 + [.0000260 τ + .0006] W/a
TEMPERATURE DIFFERENCE, 1500° F.
1100
1000
900
800
700
600
500
400
300
200
100
C = B.T.U. TRANSMITTED PER DEGREE TEMPERATURE DIFFERENCE PER SQUARE FOOT OF HEATING SURFACE PER HOUR.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
1000
2000
3000
4000
5000
6000
7000
W/a = POUNDS OF GASES PER SQUARE FOOT CROSS-SECTION OF TUBES PER HOUR.

Figure 22.

For Series II. and III.,

$$A = 1.500 + .001213\tau \tag{70}$$

$$B = .0000187\tau^{.75} + .0008 \tag{71}$$

This gives as values for C

For Series I.,

$$C = 1.000 + .00087\tau + [.0000141\tau^{.906} + .0008077]\frac{W}{a} \tag{72}$$

For Series II. and III.,

$$C = 1.500 + .001213\tau + [.0000187\tau^{.75} + .0008]\frac{W}{a} \tag{73}$$

If A be considered a constant and equal to the mean of all the A's determined by least squares as mentioned previously, then
For Series I.,

$$A = 1.6501 \tag{74}$$

For Series II. and III.,

$$A = 2.4464 \tag{75}$$

With these values of A and the values of C tabulated on pages 49 and 53 a second series of least squares solutions were made to determine B, resulting as follows:

For Series I.,

$$B = .00000238\tau^{.836} + .000618 \tag{76}$$

For Series II. and III.,

$$B = .0000260\tau^{.781} + .0006 \tag{77}$$

Using these values of A and B gives

For Series I.,

$$C = 1.6501 + [.00000238\tau^{.836} + .000618]\frac{W}{a} \tag{78}$$

For Series II. and III.,

$$C = 2.4464 + [.0000260\tau^{.781} + .0006]\frac{W}{a} \tag{79}$$

The family of curves resulting from these equations are shown in figures 21 and 22.

The results of the Babcock and Wilcox Co. experiments, using a

tube of 1.75″ inside diameter, are shown in their published bulletin as a family of straight lines similar to figures 21 and 22. The Babcock and Wilcox Co. curves can be well satisfied by the equation.

$$C = 2.20 + [.0000335\tau^{.681} + .0005]\frac{W}{a} \qquad (80)$$

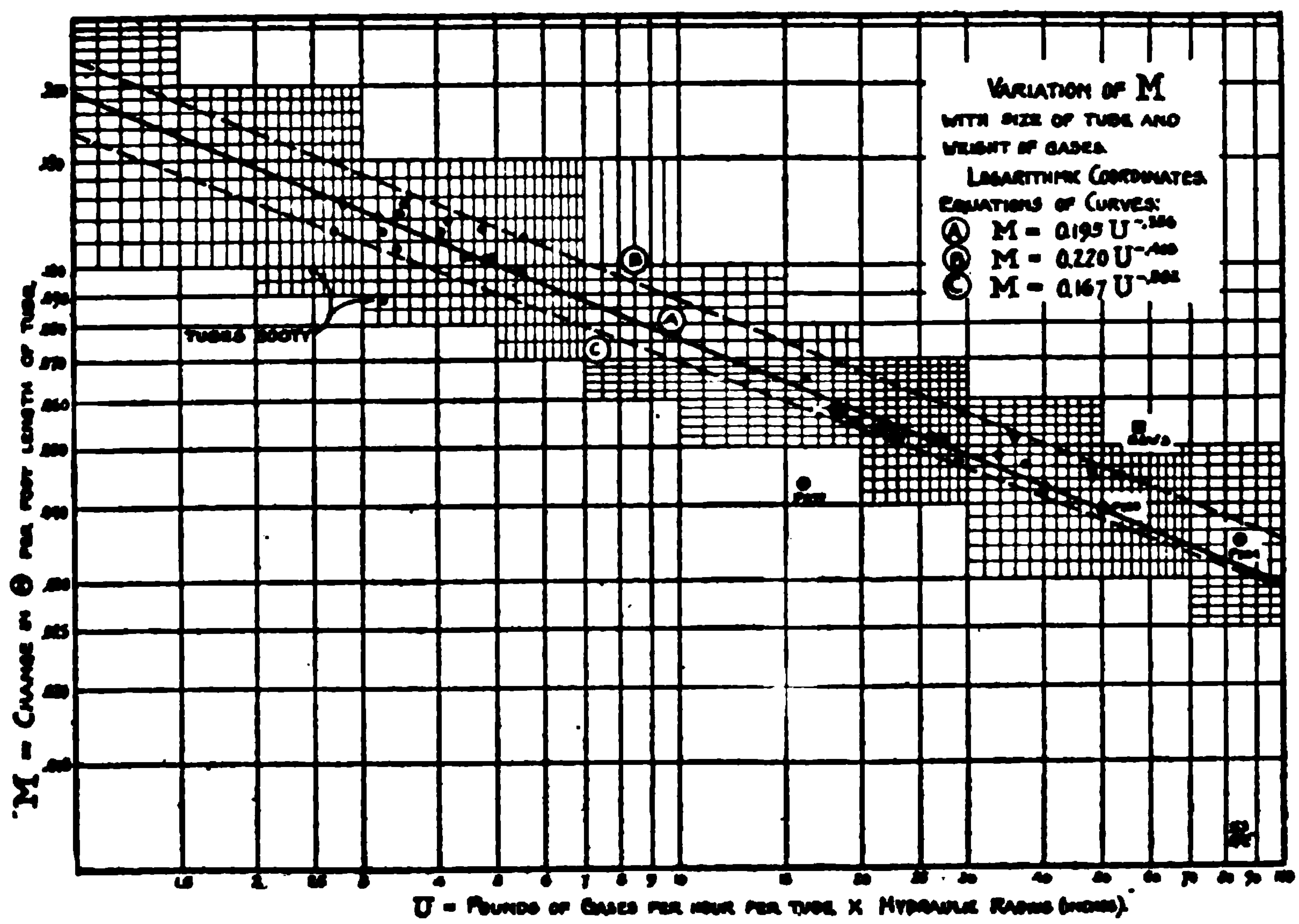


Figure 23.

Another series of experiments by the Babcock and Wilcox Co., using the same tube as before but with a 1″ outside diameter core placed centrally in the tube, gave values for C as expressed by

$$C = 3.00 + [.000290\tau^{.361}]\frac{W}{a} \qquad (81)$$

From the evidence thus far collected it seems probable,

1. That curves plotted between C and $\frac{W}{a}$ are not quite straight lines, i. e., that B is not a constant even for constant values of temperature difference.

2. That if straight lines are used to express the relation between C and $\frac{W}{a}$, the values of A and B depend upon the shape and size of the gas passage, the temperature difference and possibly also upon the physical characteristics of the gases.

GENERAL EQUATION

It has been shown that equation (21)

$$\left(\frac{H}{H_x}\right)=\left(\frac{H_0}{H_w}\right)^{e^{-mx}} \tag{21}$$

expresses the manner of the change in heat content of the gases as they pass down the tube for any single experiment. It is desirable to state the equation so that it applies to different experiments with different amounts of gas passing and with different sized tubes. For this purpose the same formula in the form of equation (22) is more easily handled.

$$\log_{10}\left(\log_{10}\frac{H}{H_w}\right)=K-Mx \tag{22}$$

where

$K=\log_{10}\left(\log_{10}\frac{H_0}{H_w}\right)$

$x=$ distance from the furnace end of the tube in feet.

$M=$ a constant for any single experiment.

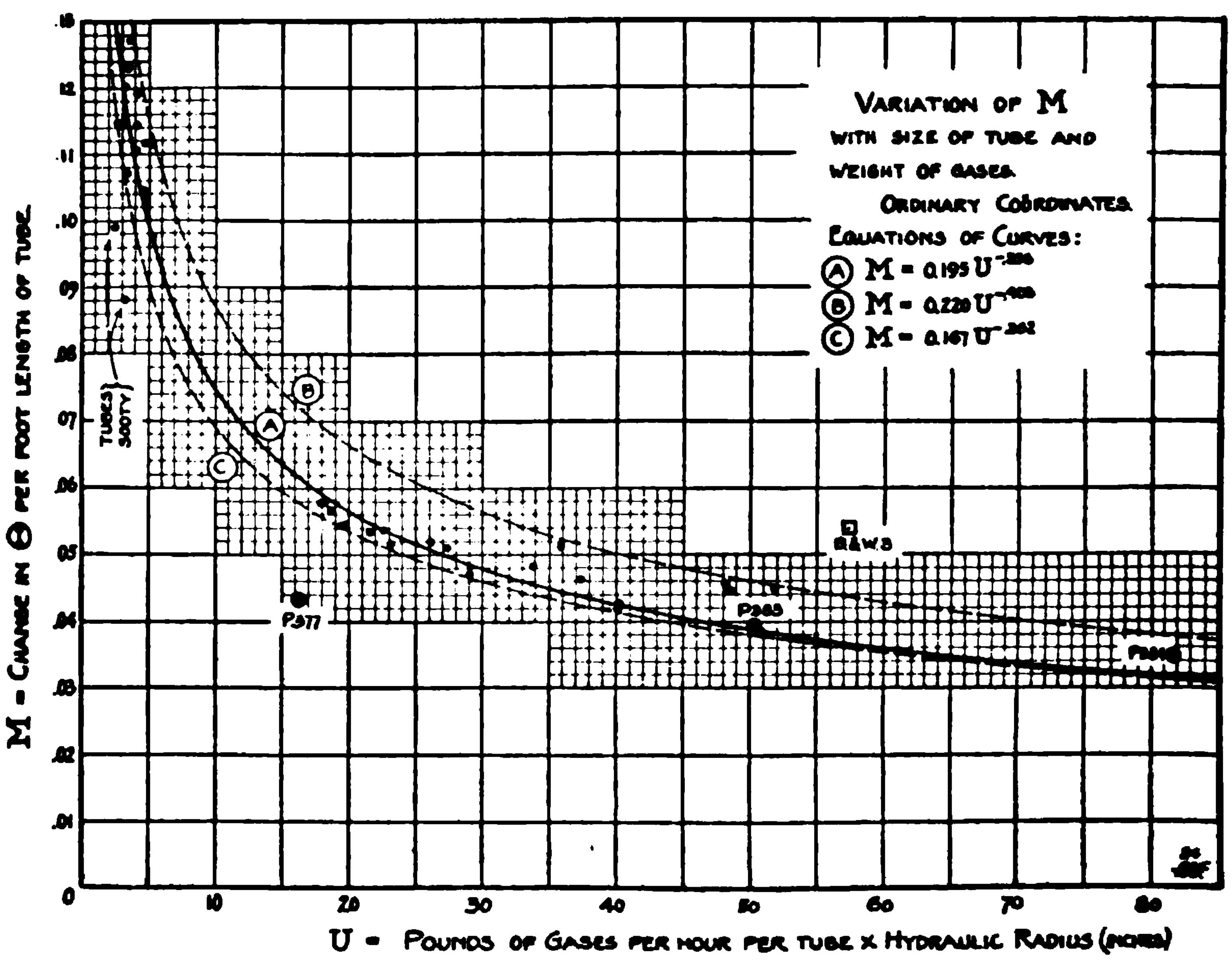


Figure 24.

Inspection of the data given on pages 48 to 55 shows that M is certainly affected by the weight of gases passing and by the size of the tube. Probably it is also affected by the physical properties of the gases, but in our experiments the gas composition did not vary sufficiently to show this. A considerable range of gas weights and experiments with two sizes of tubes give an opportunity for attempting to bring these two determining conditions together. On pages 49 and 53 are tabulated the value of M and also a quantity U, the weight of gas per tube per hour multiplied by the hydraulic radius of the tube in inches. The quantities M and U are plotted against each other in figures 23 and 24, and from these curves the empirical equation

$$M = 0.195U^{-[illegible]} \tag{82}$$

was determined as indicating the value of M with considerable accuracy. In the same figures extreme curves are drawn giving values of M as all lying between

$$M = 0.167U^{-[illegible]}$$

and

$$M = 0.220U^{-[illegible]}$$

For purposes of comparison the points for three Pennsylvania R. R. locomotive tests for which sufficient data is given to permit the necessary computations and for the Babcock and Wilcox test number 3 are also shown with the curves just mentioned. For the locomotive tests the total weight of gases passing thru the entire boiler was computed from the analyses of the stack gases and the coal consumption. This divided by the total number of tubes was taken as the weight of gases per tube in determining U. The temperatures supplied by Mr. Young were measured in a tube slightly above the center line of the boiler. This particular tube may have received more or less gas than the average amount per tube calculated, but since the gas distribution among the tubes was not known, this seemed the only assumption we could make.

Equation (22) may then be rewritten

$$\log_{10} \left(\log_{10} \frac{H}{H_w}\right) = \log_{10} \left(\log_{10} \frac{H_b}{H_w}\right) - 0.195\, U^{-[illegible]} x \tag{83}$$

where

U = pounds of gas per hour per tube multiplied by the hydraulic radius of the tube in inches.
x = distance from furnace end of tube in feet.

If the weight of gases per tube per hour is w, and the tube diameter

is d inches,

$$U = w\frac{d}{4}$$

and

$$\log_{10}\left(\log_{10}\frac{H}{H_w}\right) = \log_{10}\left(\log_{10}\frac{H_0}{H_w}\right) - 0.195\left[\frac{wd}{4}\right]^{-.\text{[illegible]}} x \qquad (84)$$

This equation is apparently applicable to all rates of gas flow and to all sizes of tubes. It indicates that the decrease in heat content of the gases increases as the weight of gases passing and the tube diameter are made smaller.

TUBE EFFICIENCIES

Equation (26), page 10, is an expression for the efficiency of the tube,

$$1 - E = \frac{H - H_w}{H_0 - H_w} \qquad (26)$$

or

$$E = 1 - \frac{H - H_w}{H_0 - H_w} \qquad (85)$$

Substituting for H, from equation (21),

$$H = H_w\left(\frac{H_0}{H_w}\right)^{e^{-mx}} \qquad (21)$$

Gives

$$E = 1 - H_w\frac{\left(\frac{H_0}{H_w}\right)^{e^{-mx}} - 1}{H_0 - H_w} \qquad (86)$$

where

$m = 2.3026\, M$

Empirical equations for determining M for any size of tube and for any rate of gas flow have been given on page 65, so that the efficiency of any tube may be estimated.

$$M = 0.195U^{-.\text{[illegible]}} \qquad (82)$$

where

M = change in $\log_{10}\left(\log_{10}\frac{H}{H_w}\right)$ per foot length of tube

U = pounds of gas per tube per hour multiplied by hydraulic radius in inches.

Assuming that the above equation for M holds for all water temperatures, efficiency curves have been plotted for several standard size boiler tubes, at several different rates of gas flow, for an initial gas temperature of 2000° F. and water temperature of 366° F. (corresponding to steam at 150 pounds per square inch gage pressure). The data used is given in tables 11 and 12.

The values of M as given in the last division of table 12 are plotted in figure 25.

Assuming that the composition of the gases by weight is CO_2, 10%; O, 12%; N, 73%; H_2O, 5% the following table of gas heat content is obtained.

TABLE 11

Constituent Gas	Heat Content Above 32° F. B. t. u. — At 2000° F. — Per Pound of Constituent	Per Pound of Gases	At 366° F. — Per Pound of Constituent	Per Pound of Gases
Co_2 10%	605	60.50	77	7.70
O_2 12%	498	59.76	75	9.00
N_2 73%	536	391.28	82	59.86
H_2O 5%	1033	51.65	152	7.60
		563.19		84.16

For gas of this composition the heat per pound to raise the temperature from absolute zero to 32° F., found as previously explained,* is 115.83 B. t. u. Then

$$H_0 = 563.19 + 115.83 = 679.02 \text{ B. t. u.}$$
$$H_w = 84.16 + 115.83 = 199.99 \text{ B. t. u.}$$

The simplest method of solving for the efficiency is to compute values of $\log_{10}$ $\left(\log_{10}\dfrac{H}{H_w}\right)$ as shown on page 39 using the values of M as given in the tables above, and then work back from these to values of H, finally substituting in the formula

$$E = 1 - \frac{H - H_w}{H_0 - H_w} \tag{85}$$

*See page 43.

TABLE 12

Nominal diameter of tube		1″	2″	3″	3½″	4″
Actual internal diameter, inches		0.810	1.810	2.782	3.260	3.732
Cross sectional area in sq. ft.		.003578	.017868	.042213	.057964	.075964
Hydraulic radius, inches		.2025	.4525	.6955	.8150	.9330
Weight gases per tube per hour in order to give $\frac{W}{a}$ as indicated	$\frac{W}{a}$					
	2000	7.16	35.74	84.43	115.93	151.93
	4000	14.31	71.47	168.85	231.86	303.86
	6000	21.47	107.21	253.28	347.78	455.78
	8000	28.62	142.94	337.70	463.71	607.71
	10000	35.78	178.68	422.13	579.64	759.64
Values of U for $\frac{W}{A}$ as indicated	2000	1.449	16.17	58.72	94.48	212.6
	4000	2.898	32.34	117.44	189.0	283.5
	6000	4.347	48.51	176.2	283.4	425.2
	8000	5.796	64.68	234.9	377.9	567.0
	10000	7.245	80.25	293.6	472.4	708.7
Values of M for $\frac{W}{a}$ as indicated	2000	.1709	.07241	.04574	.03862	.03343
	4000	.1335	.05665	.03574	.03017	.02619
	6000	.1156	.04896	.03094	.02612	.02261
	8000	.1043	.04419	.02792	.02358	.02041
	10000	.09634	.04082	.02579	.02178	.01885

For all the cases involved in the problem as stated above,

$$\frac{H_0}{H_w} = \frac{679.02}{199.99} = 3.3953$$

$$R_0 = \log_{10} \left(\frac{H_0}{H_w}\right) = .53088$$

$$\Theta_0 = \log_{10} R = 9.72500$$

Table 13 gives the tube efficiencies up to the end of each two foot section measured from the furnace end of the tube for the rates of gas flow previously selected. This is equivalent to the efficiencies

of tubes varying in lengths by two foot increments, up to 20 ft. long. The same data is shown in curves on figures 26 to 30 inclusive. It is to be noted that these figures take no account of heat losses by radiation from the boiler surrounding the tube, and only charge against

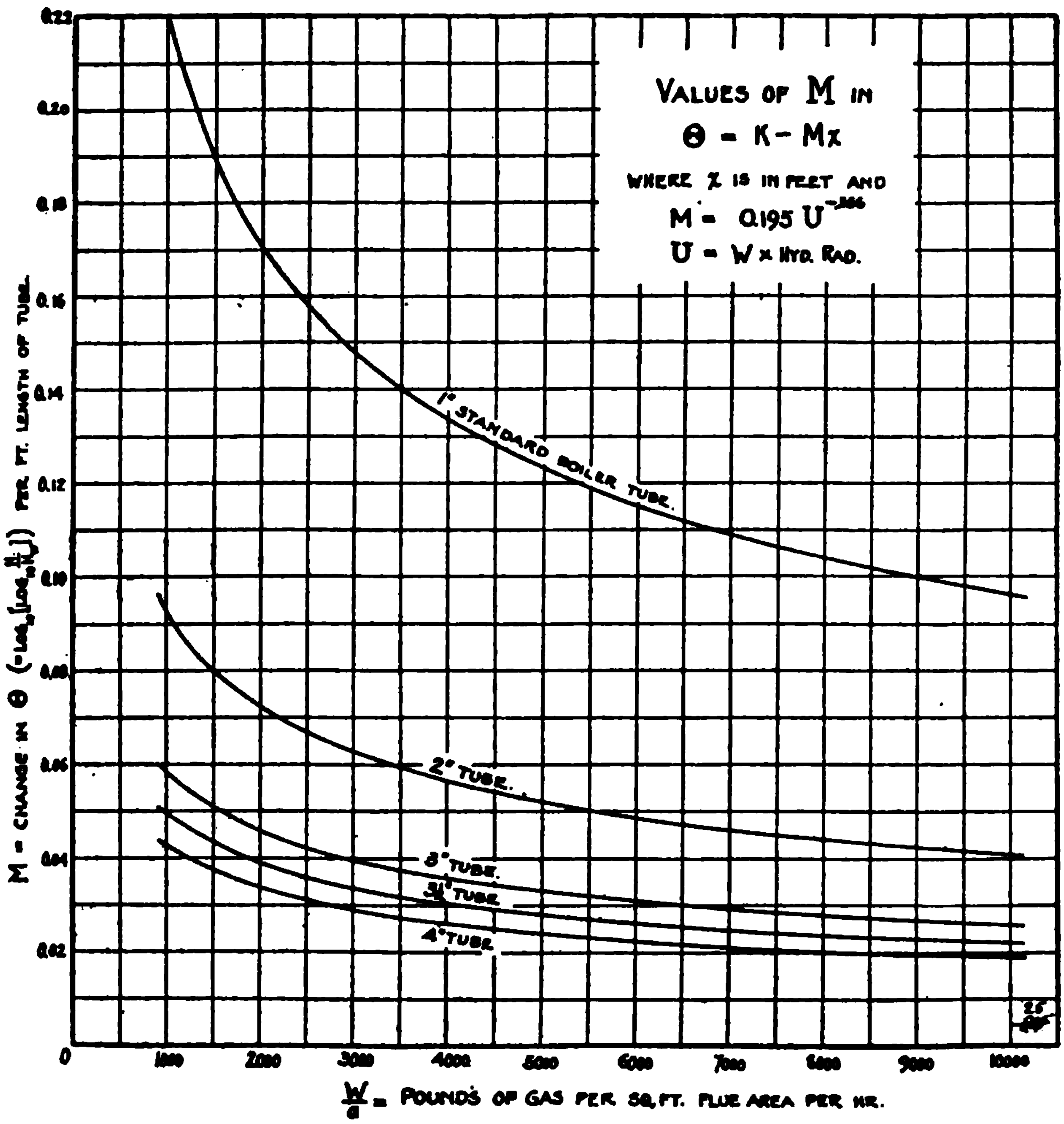


Figure 25.

the tube the heat actually available for transmission to the water, i. e., the heat above the temperature of the boiler water. The very high efficiency of the small tubes is of course somewhat counteracted by the power required to produce the necessary draft and also by the difficulty in keeping the small tubes clean. The comparatively slight decrease with increased rates of driving is also of interest. This is only another way of saying that the boiler capacity is nearly proportional to the weight of gases passing. It may very often pay well to operate at the slightly lower efficiency to secure a great increase in capacity.

TABLE 13. TUBE EFFICIENCIES

Tube Size	Tube Length, Feet	Tube Efficiency for W/a as Indicated				
		$W/a = 2000$	4000	6000	8000	10000
1″	2	68.9%	60.9%	56.2%	52.5%	50.9%
	4	88.0	82.0	78.1	75.1	73.2
	6	94.5	91.1	88.3	86.0	64.5
	8	97.7	95.4	93.5	91.8	90.7
	10	99.0	97.6	96.3	95.1	94.3
	12	99.5	98.7	97.9	97.0	96.5
	14	99.8	99.3	98.8	98.2	97.8
	16	99.9	99.6	99.3	98.9	98.6
	18	100.0—	99.8	99.6	99.3	99.1
	20	100.0—	99.9	99.7	99.6	99.4
2″	2	41.7	34.7	31.0	28.5	26.7
	4	63.6	55.5	50.8	47.5	45.1
	6	76.4	68.7	64.1	60.6	58.1
	8	84.2	77.6	73.2	69.9	67.4
	10	89.2	83.6	79.7	76.8	74.4
	12	92.5	87.8	84.5	81.9	79.7
	14	94.8	90.9	88.0	85.7	83.8
	16	96.3	93.2	90.8	88.7	87.0
	18	97.4	94.8	92.7	91.0	89.5
	20	98.1	96.1	94.3	92.8	91.4
3″	2	29.4	24.1	21.3	19.5	18.2
	4	48.6	41.2	36.6	34.3	32.3
	6	61.6	53.8	49.1	45.9	43.5
	8	71.1	63.2	58.4	55.1	52.5
	10	77.8	70.4	65.7	62.4	59.8
	12	82.7	75.9	71.5	68.4	65.7
	14	86.5	80.3	76.2	73.1	70.6
	16	89.4	83.8	80.0	77.1	74.8
	18	91.6	86.6	83.1	80.4	78.2
	20	93.3	88.9	85.7	83.2	81.1
3½	2	25.5	20.7	18.3	16.7	15.6
	4	43.5	36.4	32.6	29.9	28.2
	6	56.3	49.3	43.8	40.9	38.5
	8	65.7	57.6	52.9	49.6	47.1
	10	72.7	64.9	60.2	56.8	54.2
	12	78.2	70.7	66.1	62.8	60.2
	14	82.4	75.5	71.1	67.8	65.2
	16	85.7	79.3	75.2	72.0	69.6
	18	88.3	82.5	78.6	75.6	73.2
	20	90.4	85.2	81.5	78.6	76.4
4	2	22.7	18.3	16.1	14.7	13.7
	4	39.2	32.7	29.1	26.8	25.1
	6	51.5	44.0	39.6	36.8	34.6
	8	60.9	52.9	48.3	45.1	42.7
	10	68.2	60.3	55.4	52.1	49.6
	12	73.9	66.2	61.4	58.0	55.4
	14	78.9	71.1	66.4	63.1	60.5
	16	82.1	75.2	70.7	67.4	64.9
	18	85.1	78.7	74.4	71.2	68.7
	20	87.5	81.5	77.5	74.4	72.0

THE BABCOCK AND WILCOX CO. TESTS*

While our tests were in progress, a similar series was being carried out by the Babcock and Wilcox Co. A copper tube, 2 inches internal diameter, 0.134 inch thick and 20 feet long formed the gas passage. This was surrounded by twenty jackets each approximately one foot

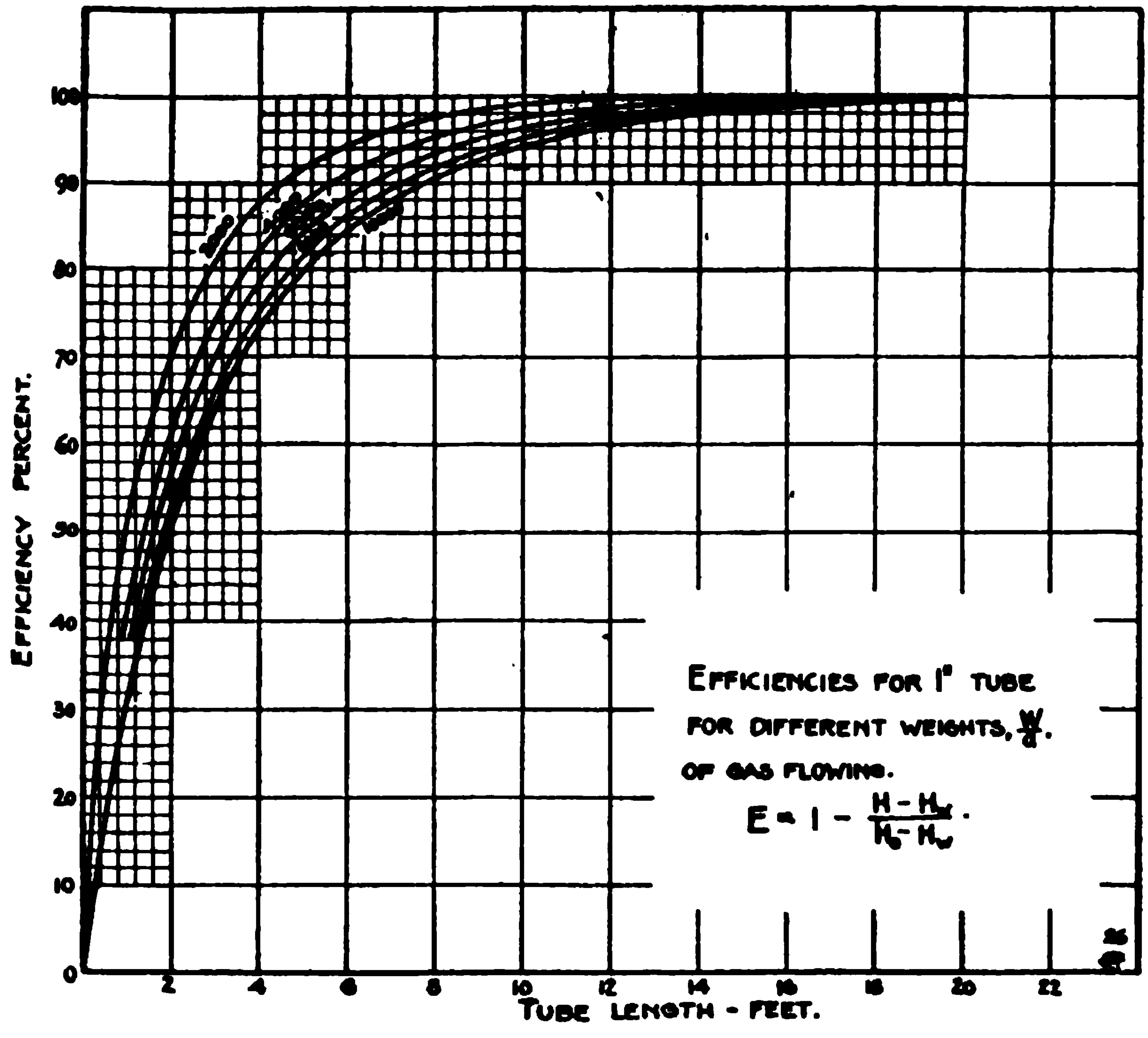


Figure 26.

long, through which water was continually circulated. No steam was formed in the jackets. The water supply temperature was maintained

*This description is obtained from a bulletin issued by The Babcock and Wilcox Co., giving complete description of the tests and a comprehensive resumé of the results.

constant during each test at 140-145° F., and the rate of water flow to the different jackets was adjusted to give the same exit water temperature from two adjacent jackets. During a test the water passing thru each jacket was caught in a bucket and weighed; the weight, together with the observed rise in temperature, giving the amount of heat observed in each jacket.

After leaving the heat transfer tube the gases were partially cooled by passing thru a helical coil immersed in water, and then to a dew

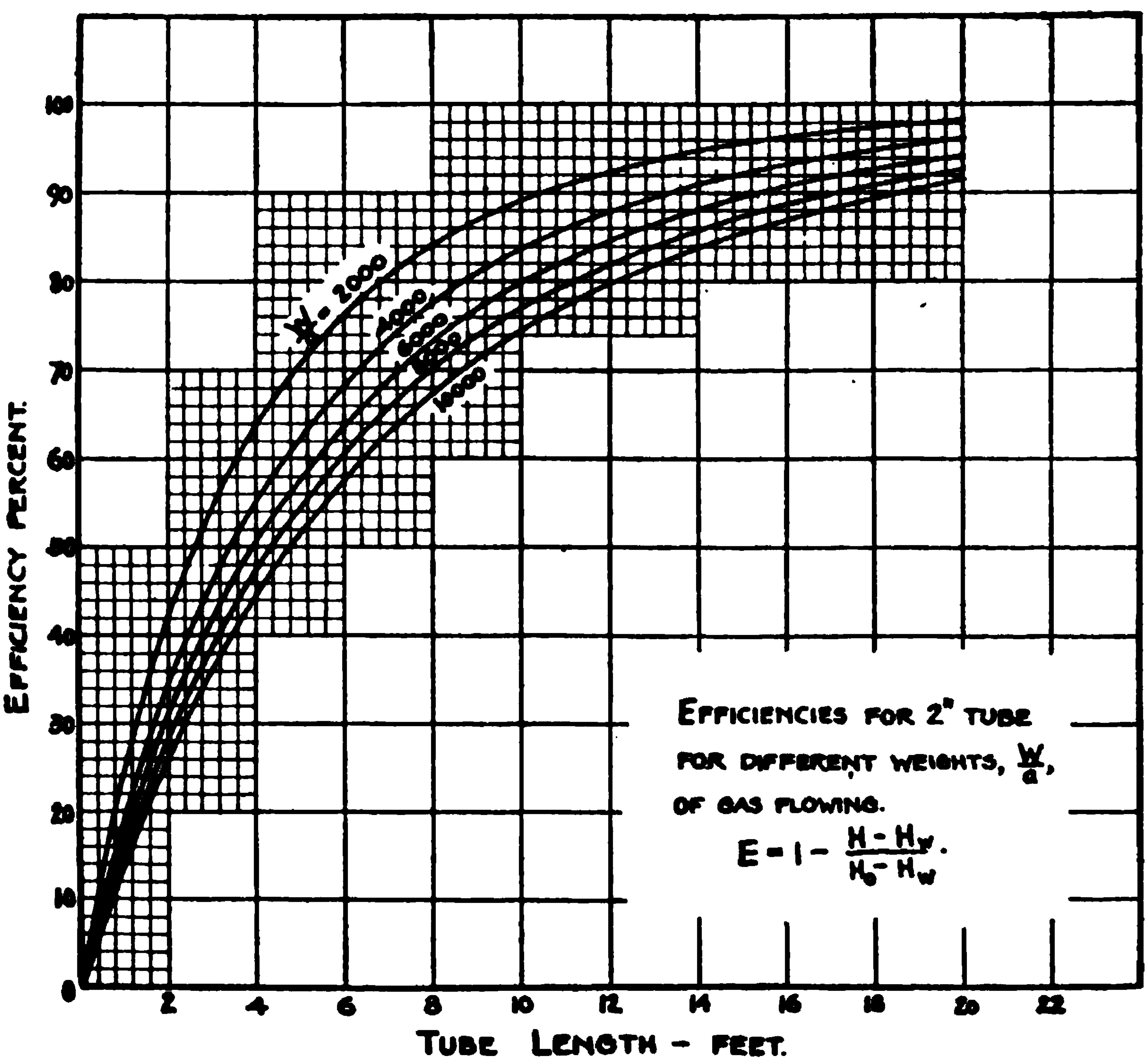


Figure 27.

point apparatus in which it was further cooled just until the dew point was reached as shown by the beginning of condensation of moisture on a highly polished nickel mirror. The dew point temperature thus obtained supplies data for determining the weight of water vapor present in each cubic foot of gas. This, with the weights

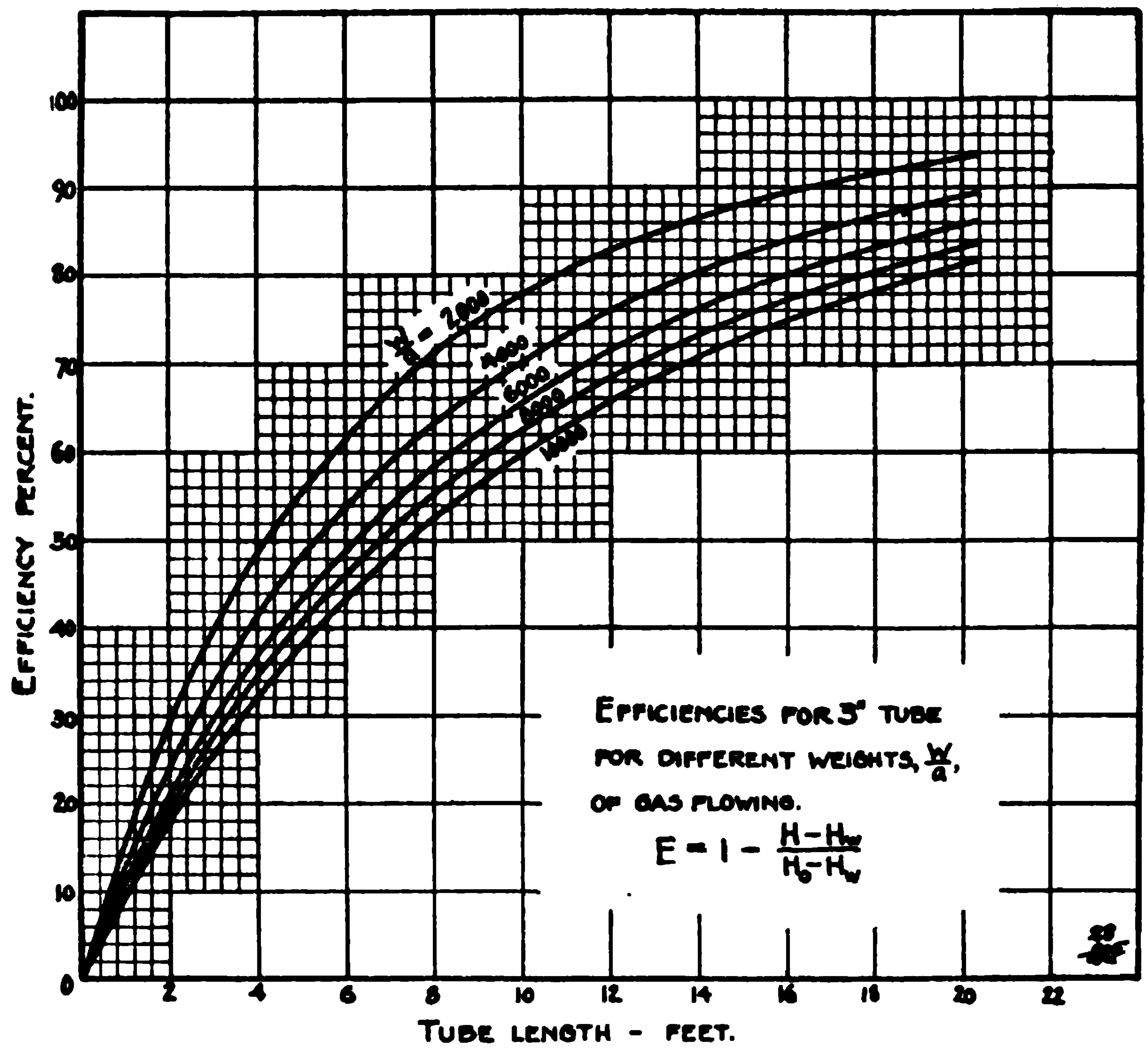


Figure 28.

of the various gaseous constituents as determined by the ordinary volumetric analysis, makes it possible to compute the composition of the gases in per cents. by weight. The specific heat of the composite gas at different temperatures was then determined by equations similar to those used by the authors.

The gas weight was determined by the gas temperatures at entrance and exit to the gas cooler, the mean specific heat of the gases between the temperatures and the heat absorbed by the water passing thru the gas cooler. The temperature of the gases passing thru the boiler tube were computed at each jacket by reckoning backward from the gas temperature at the exit end in the same manner as was used by the authors.

These experiments appear to have been carried out with great care and accuracy. It is to be regretted that the water in the jackets was not allowed to boil in order to more nearly simulate actual boiler

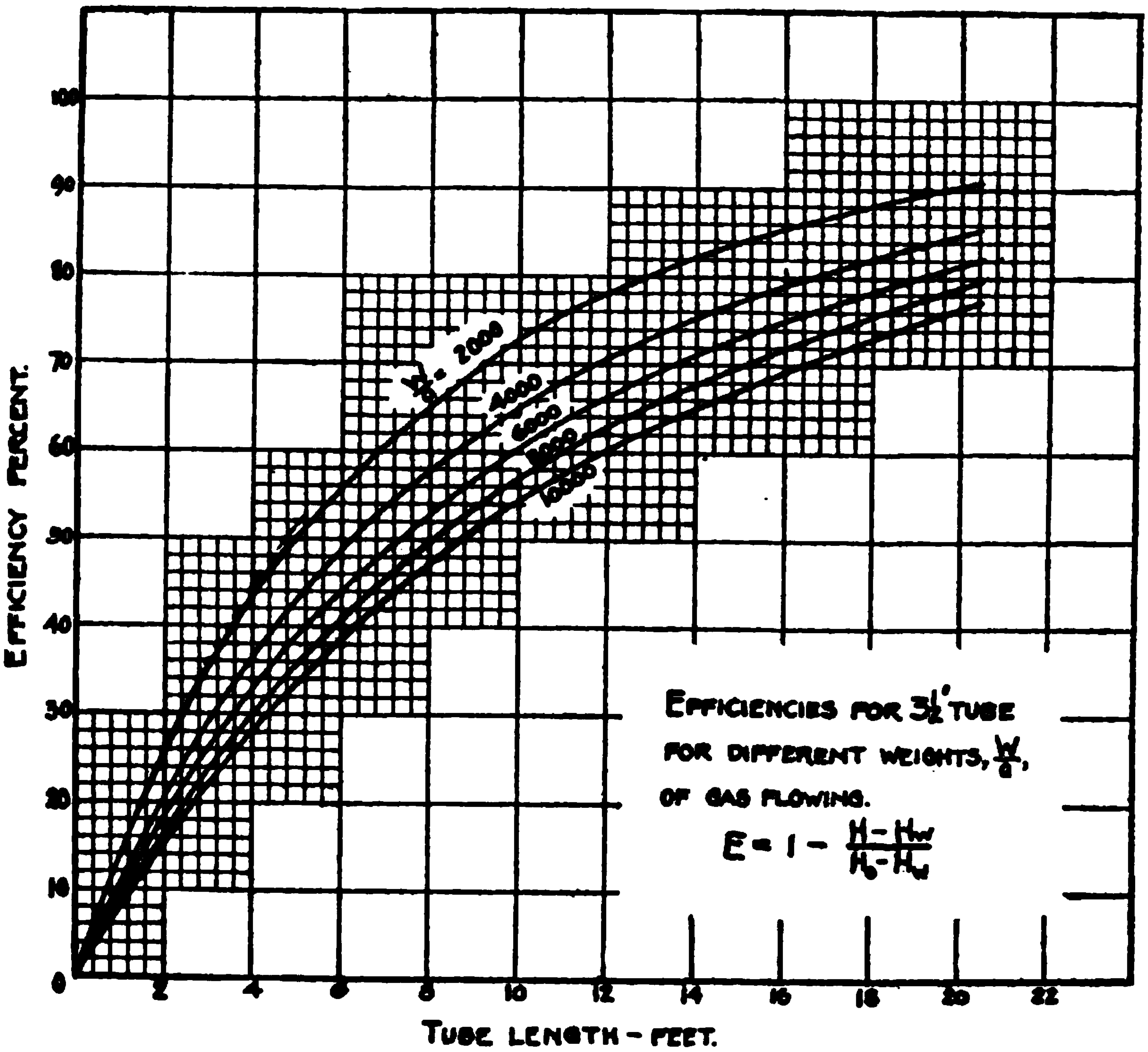


Figure 29.

conditions. No attempt was made by those responsible for the Babcock and Wilcox experiments to obtain a general equation which would express the relation between the various conditions affecting the experiments. It was assumed that an equation of the form which we have called the Bureau of Mines formula* could be used, but it is clearly shown that the quantity B is not a constant, but a variable depending upon the rate of gas flow. A fair equation expressing the results of these experiments is given on page 61 (equation (30)). In the bulletin describing the tests it is stated that while equation (2) holds approximately, the straight line represented by this equation is really a secant or tangent to the real curve which bends from the line in both directions. This confirms the observations of our own experiments (see page 55). Furthermore it is stated that while these experiments give a value of $a = 2.2$, for a range of gas weights

*Equation (2).

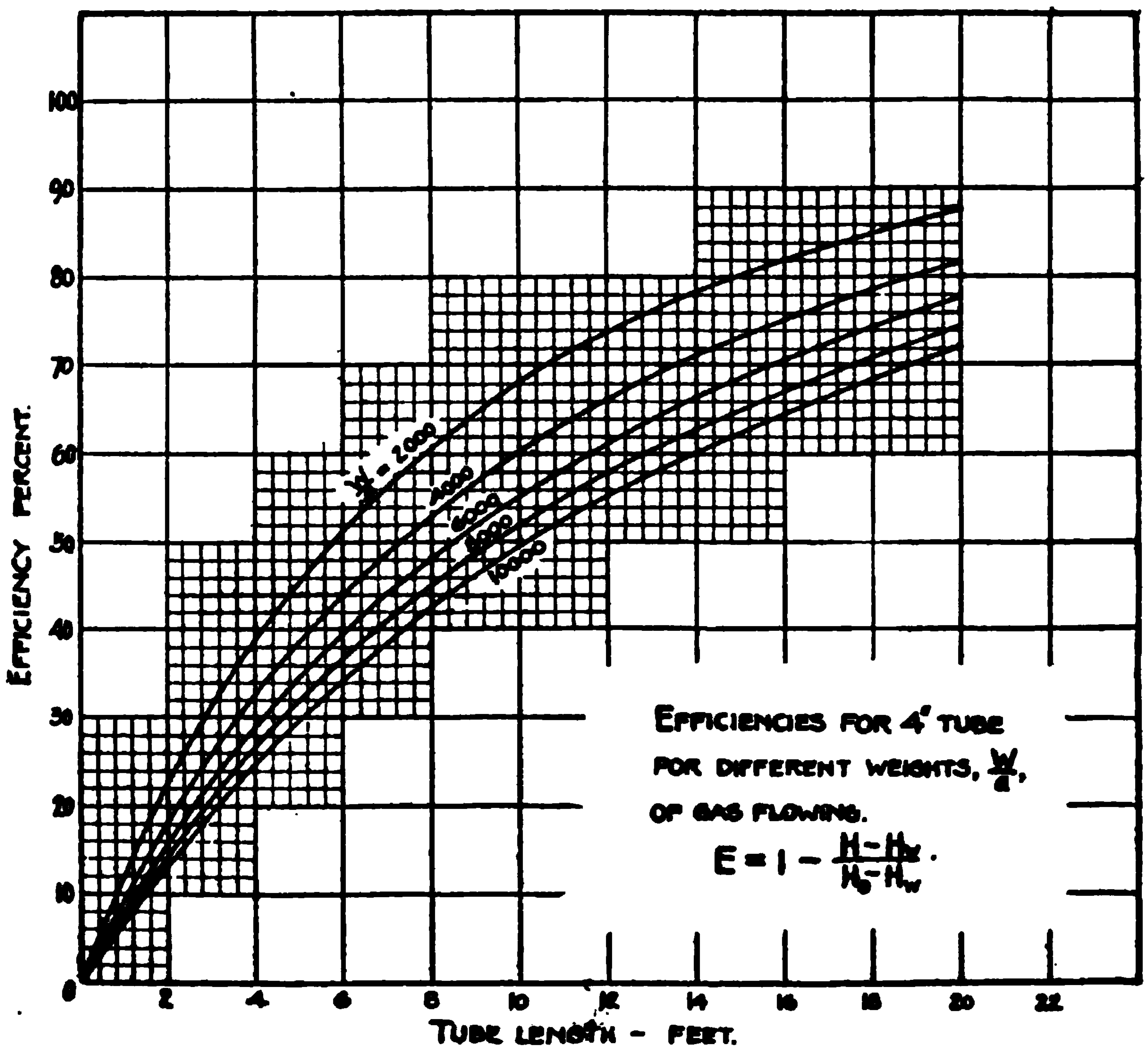


Figure 30.

from $\frac{W}{a} = 4000$ to $\frac{W}{a} = 14000$, this value of *A* would have appeared less had a lower set of weights been used, and had a higher set of weights been used, *A* would have appeared greater. In other words, *A* is not a constant.

It thus seems that these very accurate experiments completely confirm our thesis, that the heat transfer rate cannot be accurately expressed as a straight line relation with the temperature difference.

TABLE 14.

BABCOCK AND WILCOX CO'S. TEST NO. 3.

20 SECTIONS, EACH 1 FT. LONG. LBS. GAS PER MINUTE, 1.9117. WATER TEMPERATURE (AVERAGE), 150.69° F. EXIT GAS TEMPERATURE, 388° F. RADIATION CORRECTION, 0.5 B.T.U. PER MINUTE. H_w = 281.50 B.T.U., H_0 = 1435.41 B.T.U.

COPPER TUBE, 2.00 INCHES INTERNAL DIAMETER.

FEET FROM FURNACE.	B.T.U. ABSORBED PER HR., AS PER TEST.	B.T.U. ABSORBED PER HR., CORRECTED.	B.T.U. LEAVING EACH SECTION PER MIN. = H	$R = \log_{10} \frac{H}{H_w}$	$\theta = \log_{10} R$	DIFFERENCES IN θ	TEMP. DIFF. BETWEEN GAS AND WATER = T	$\log_{10} T$	DIFFERENCES IN $\log_{10} T$
	COPIED FROM B&W BULLETIN.								
0			1435.41	0.7075	9.8497				
1	9826.82	—	1271.13	0.6547	9.8161	0.0336	1877	3.2735	
2	7091.57	7140.1	1152.44	0.6121	9.7869	0.0292	1667	3.2219	0.0516
3	5885.29	6180.8	1053.85	0.5733	9.7584	0.0285	1481	3.1706	0.0513
4	5548.82	5399.6	960.98	0.5332	9.7269	0.0315	1318	3.1199	0.0507
5	4832.14	4655.3	879.83	0.4949	9.6945	0.0324	1174	3.0697	0.0502
6	4029.82	4050.6	812.17	0.4602	9.6629	0.0316	1047	3.0200	0.0497
7	3517.51	3530.3	753.04	0.4273	9.6308	0.0321	934	2.9704	0.0496
8	3196.24	3082.2	699.27	0.3962	9.5968	0.0340	835	2.9217	0.0487
9	2654.40	2696.5	651.63	0.3665	9.5640	0.0328	747	2.8733	0.0484
10	2359.90	2361.4	614.70	0.3392	9.5304	0.0336	669	2.8254	0.0479
11	2046.38	2072.2	580.09	0.3141	9.4970	0.0334	601	2.7789	0.0465
12	1773.83	1821.5	550.03	0.2909	9.4637	0.0333	540	2.7324	0.0465
13	1610.26	1603.9	522.69	0.2688	9.4294	0.0338	485	2.6857	0.0467
14	1412.21	1414.7	498.65	0.2483	9.3950	0.0344	437	2.6405	0.0452
15	1246.88	1249.9	477.57	0.2294	9.3605	0.0345	395	2.5966	0.0439
16	1084.78	1106.2	458.79	0.2121	9.3266	0.0339	356	2.5515	0.0451
17	979.49	980.7	441.97	0.1959	9.2921	0.0345	322	2.5079	0.0436
18	870.36	871.0	426.96	0.1809	9.2575	0.0346	292	2.4654	0.0425
19	782.22	774.8	423.42	0.1669	9.2225	0.0350	264	2.4216	0.0438
20	772.97	—	400.04	0.1626	9.1836	0.0389	237	2.3748	0.0468

GAS ANALYSIS, PERCENT BY WEIGHT,
CO_2, 14.9%; O_2, 6.8%; CO, 0%; N_2, 70.4%; H_2O, 7.9%.

THE UNIVERSITY OF MISSOURI BULLETIN

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